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OPERATIONS AND TO THE

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WATER POWER APPARATUS
WITH RULES AND TABLES BEARING THEREUPON

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Intending Users of Hydraulic Machinery*

BY

FRED. A. BRADLEY
CONSULTING ENGINEER

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PREFACE

THAT an ounce of Practical knowledge, intelligently applied, is worth a pound of Theory, may be accepted as an Axiomatic truth. At the same time, it must be recognised that a combination of Theoretical and Practical acquaintance with any subject, affords the possessor immense advantages in making the best use of his knowledge of the subject in question.

In no branch of Science has greater progress been made in one Century than in that of "Engineering," and so various and complex are the subjects with which an Engineer of the present day must be in touch, that it is an utter impossibility for any man (who does not devote almost exclusive attention to one only of the branches of his profession) to keep himself posted in the numerous matters that he must of necessity recognise.

I venture to assert that few subjects are less generally included in an average Engineer's repertoire of knowledge than that of Hydraulics, unless his practice has led him to an especial study of the subject.

During the past forty years' Practice as an Engineer in various parts of the world I have been frequently impressed by finding, even amongst experienced Engineers (apart from ordinary users and purchasers of Hydraulic machinery), only a very superficial knowledge of some of the most important considerations relative to Pumping and Water Power.

I have also observed that there appears to be a dearth of Simple, Practical Literature treating upon these subjects.

Although many works have been written embracing the subject of Hydraulic work, Pumping appliances, and the application of Hydraulic Power, they usually treat of some especial feature or branch of the subject, or of mechanical details of construction. Or they are too costly to be within the reach of Mechanics, Students, and others to whom a general explanation of the Laws of Hydraulics and their practical application would be serviceable. I venture to hope that the present Treatise may meet a necessity in this respect.

Having been for a number of years occupied in arranging for, and directing the construction of, Pumping and Hydraulic Power works for a variety of purposes, I have necessarily recognised the points to which the greatest attention should be given, as well as those in respect of which the most misconception exists, so that even Engineers in advanced practice may possibly find items of use and interest in the following pages. I have no intention of entering into the higher grades of the subjects herein treated of, wishing to confine the subject-matter to a small space, and giving only such Data as may enable those desiring to pursue any of the subjects further to do so intelligently and methodically.

In these times of keen business competition it is incumbent upon every Manufacturer to extol the merits of his own goods, and it is equally the rôle of the intending Purchaser to obtain the class of goods best suited to his needs.

Dealing with our own Subject, anyone having in view the use of Pumping or Water Power plant, applies to some firm of Manufacturers, who (it may be taken for granted) recommend such apparatus as they are interested in. It may be the best for the purpose, or other systems or machines may be more suitable. If the purchaser can go about the business with a reasonable amount of knowledge as to the plant best fitted for his purpose, he is in a position to decide with judgment, and can confidently approach the Manufacturers of the especial class of apparatus he needs. A study of the following Treatise should serve to assist such intending users of Hydraulic Machinery, or those engaged in erecting same, to lay out their work with confidence in the result.

In order that the book may be easily within the reach of all, the various subjects have been treated of as concisely as possible, costly illustrations have been avoided, and such outline sketches only given as shall serve to elucidate the matter they refer to, though not intended as guides to actual Mechanical construction, such detail being outside the province of this work.

FRED. A. BRADLEY.

DURBAN, NATAL,
February 1912.

PUMPING
AND WATER POWER

CHAPTER I

HYDRAULICS

As the Title of this treatise implies, the proposal is to consider the subject of Hydraulics, principally in relation to Pumping Work and to Hydraulic Power, and to offer a sufficient explanation of the Laws governing such Applications, to enable those interested to work upon practical lines in dealing with these branches of Mechanical work.

The object sought is not so much that of Mathematical exactitude of Calculations, as of furnishing those studying any of the subjects treated of—(with a view to their practical application)—with Ready rules for arriving at approximately correct results.

Although many of the same conditions that apply to Water are equally applicable to other Liquids, it is proposed to deal only with the subject as relative to Water, and Water power.

There are three important Laws governing Hydraulics which immediately concern this matter, and should be fully understood by all interested in the subject.

First.—*Water will always seek its own level.*

Second.—*The pressure of Water is equal in all directions.*

Third.—*The pressure of Water is in direct proportion to its depth or height, irrespective of its volume.*

First.—*Water will always seek its own level*, and that level will be the *lowest* to which it can attain.

It does not matter how tortuous a path it has to go, or how far it has to travel, it will find its way, unless it should be obstructed by artificial means, or unless it finds outlet at a *lower level* than its *starting-point.*

This Law is accountable for many Natural Phenomena, which it is needless now to refer to, since they do not largely concern the matters under present study, but its bearing upon the behaviour of water, when confined in vessels or flowing through pipes, is material to our subject.

If a number of vessels of various shapes and capacities be all connected together at their lower ends, as in fig. 1, and water be poured into any one of these vessels at the top, it will be found that it will run throughout the whole range of the vessels until it reaches the *same level* in all of them, irrespective of their several shapes and capacities. Moreover, if any opening, however small, be made in the lower part of any one of the vessels, the whole body of water will find exit at such point in search of a *lower level* still.

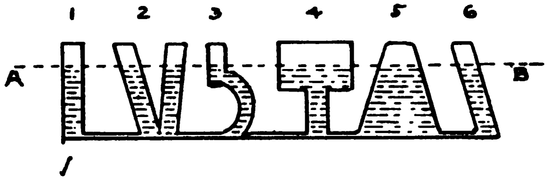


FIG. 1.

Second.—*Pressure of Water is equal in all directions.*

Water presses Downward, Sideways, and Upwards with equal energy. When unconfined it is prevented from rising by the Pressure of the Atmosphere unless forced by artificial means, but remove that restraining force and it will press upwards as readily as downwards.

When confined in a vessel closed on all sides. pressure brought to bear upon it at any point will cause it to exert equal force in all directions. So long as such pressure is continued, water would issue with equal energy from openings made in any part of the containing vessel. Thus, if a large water-tight bag be filled with water, and securely closed, if pressed upon by the hand, the water would issue in jets of equal force, or velocity, from incisions made in top, at ends, or sides, or at bottom. Again, if a Piston be fitted to work in a Cylinder, as in fig. 2, and the cylinder be partly filled with water, pressure being then brought to bear upon the Piston would cause water to flow with equal velocity from openings made simultaneously at any point, as C in the piston, and D in the cylinder, and the water would continue so to issue until the piston was forced to the bottom of the cylinder.

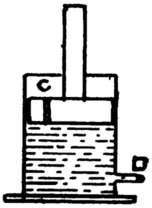


FIG. 2.

The measure of the energy of such issuing jet is readily determined thus:—Presuming that the area of the Piston is 20 circular ins., and that a pressure of 1 lb. is exerted upon the piston to force it downward, then the issuing force of the jets would be $\frac{1}{20}$ of a lb. per circular inch.

In other words, if the openings are made 1 circular in. in size, it would take a pressure of $\frac{1}{20}$ of a lb., applied at either opening, to stop the flow, so long as a pressure of 1 lb. is employed to force the piston down. If a force of 2 lbs. be employed, then the issuing jet would have a pressure of $\frac{1}{10}$ of a lb. And this would be the case wherever the openings are situated, either in the cylinder or the piston, and whether the jets issue *upwards*, *sideways*, *or downwards.*

Third.—*The pressure of Water is in proportion to its vertical height or depth*, *irrespective of its volume.*

This is probably the most important, and at the same time the least understood, of the Laws relating to Hydraulics. It applies to water at rest, as well as to water in motion, and is as applicable to an ocean as to a glass of water. The non-recognition, or ignorance, respecting this property of water is responsible for a great number of serious accidents, as well as being the cause of large expenditure in the execution of works, that might have been avoided, had due attention been given to it.

It is frequently taken for granted that the pressure exerted by a body of water largely depends upon its extent, quantity, or volume. The *weight* of any given quantity of water, of course, is so influenced, but not the pressure it would produce upon any given surface.

Let A and B, fig. 3, represent two Water Vessels, of the same height from *c* to *d*, and each having the same area of base *e f* to *e' f'*, but the vessel A having a neck of small size, whilst B is much larger at the top than at the bottom.

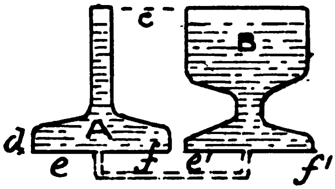


Fig. 3.

If both vessels be filled with water the pressure upon the base will be the same in either case, and in A the total pressure upon the base *e f* will be much *greater* than that due merely to the actual *weight of water* contained in the vessel. On the other hand, in the case of the vessel B the total pressure upon the base *e' f'* will be much *less* than that due to the *weight* of the water.

No matter to what height the neck of A or the large part of B be extended, if the height of each vessel be made the same, then the pressure upon their respective bases will be still *alike*. Such pressure will be in exact proportion to the *vertical height* of each, and this (for approximate mental calculation) may be taken at ½ lb. per sq. in. of area of the base *e f* or *e' f'*, for each foot in height from base to water level. More exactly, the approximate pressure is $\frac{3}{7}$ of a pound per sq. in., or the actual pressure ·4335 lb. per sq. in. To simplify calculations, the pressure will be assumed to be ·434 lb. per sq. in. for each foot of vertical height in the following notes and examples, which is sufficiently exact for all practical purposes. As a proof that the pressure is alike on the bottom of each vessel, presume that a small pipe, as shown in dotted lines in fig. 3, be so fixed as to connect the bottoms of the two vessels, it would be found that the water levels in each vessel would still remain the same. If the greater weight of water in vessel B gave a greater pressure than the smaller weight in A, then the water would be forced into A until it overflowed, and it would continue to overflow until the same *weight* of water remained in B as was contained in A, but that does *not* take place, and would not take place, no matter to what height the vessels might be extended.

Thus it will be seen how mistaken is the very common supposition that the pressure of water to be obtained from a large elevated tank would be greater than that from a smaller one at the same elevation, or that more pressure per square inch can be obtained by using a large pipe from a water supply than would be the case by using a smaller pipe (leaving the question of *friction* at present out of consideration).

Further to illustrate the bearing of this most important Law governing the behaviour of Liquids:—Let N and P, fig. 4, be supposed to represent two water-tight Casks, 2 ft. in height, standing upon a solid base. Into N is fitted a pipe 1 in. in diameter and 40 ft. in height. Into P is fitted a pipe 12 ins. in diameter and 40 ft. high. These pipes and casks being each filled with water to the tops *g* and *h*, then the pressure *per square inch* brought to bear upon each Cask would be found to be precisely the same upon the tops, sides, and bottoms respectively, although the total *weight* of water bearing upon the bottom of the cask P would greatly exceed that bearing upon the bottom of N.

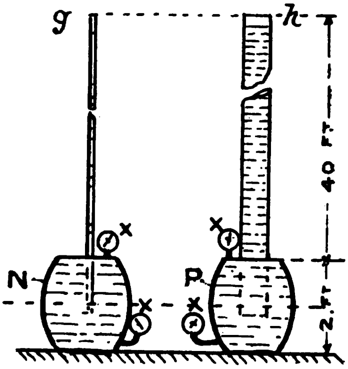


FIG. 4.

If pressure gauges were fixed at *x x x x*, they would be found to register the same pressure in pounds per square inch all round (save that the lower gauges would register about 1 lb. more than the upper ones, due to the 2 ft. difference in their height).

This pressure would be $40 \times {\cdot}434 = 17\frac{1}{3}$ lbs. per sq. in., and since water presses equally in all directions, this force would be exerted upon every square inch of the superficial area of the Casks.

If, say, another 40 or 50 ft. of 12-in. pipe be added to the pipe on Cask P, a pressure of 35 or 40 lbs. per sq. in. would be brought to bear upon the cask, and it would probably be rent to pieces, but *no sooner* than would be the case with Cask N, if another 40 or 50 ft., of even ¼-in. pipe, be added to the height of the pipe leading thereto. As before pointed out, the *dead weight* upon the bottom of cask P would be greatly in excess of that upon the bottom of cask N. The weight of water in 1 ft. of pipe of 1 cylindrical in. area = ·2842 lb.; that in 1 ft. of pipe 12 cylindrical ins. in area = 49·1 lbs. So that in addition to the weight of water in the cask itself, the bottom of N would have to sustain upon every square inch a weight of 40 ft. × ·2842 = 11·36 lbs., that of P a weight of 40 ft. × 49·1 = 1964 lbs. So that, although at first sight it would appear as if the Cask P would have to sustain a much greater pressure due to the extra body of water in the 12-in. pipe than the Cask N would be subjected to by the smaller column, this extra weight is found to affect the *bottom* of the cask only, tending to force it out if unsupported.

It follows, then, that in order to ascertain the amount of pressure upon any given surface due to a column of water, all that is required is to multiply the *square inches* of the surface pressed upon, by the vertical height of the column or body of water in feet, and by ·434 (or by the fraction $\frac{3}{7}$), or the *square feet* in the surface pressed upon by the vertical height of column in feet, and by 62·5 lbs. Or more readily for mental calculation (but not quite so correctly), take *one-half* of the height of the column in feet as representing pounds pressure per square inch, and multiply into square inches of area pressed upon.

From the foregoing remarks it will be seen that a large column of water can be balanced by a vastly smaller one, and that without regard to their relative areas.

If two Stand-pipes (see fig. 5) R and S, of 2 ins. diameter and 2 ft. diameter respectively, and both 50 ft. high, be connected together at bottom by a pipe P (the diameter of which is immaterial), and both be filled with water, then the water column in R will balance the water column in S, so that the same level is maintained in each. The weight of water in the 2-in. diameter pipe $R = 2^2 \times 50 \times {\cdot}341$ lb. = 68·20 lbs. The weight of water in the 2-ft. diameter pipe $S = 24^2 \times 50 \times \cdot 341$ lb. = 9820 lbs., but still they balance.

The pressure per square inch due to the head of water at the bottom of either stand-pipe = 50 ft. × ·434 lb. = 21·7 lbs. per sq. in. Now suppose the large stand-pipe S to be cut off at *w w*, as in fig. 6, the upper part removed, and a weighted cover, water-tight, laid over the opening at *x*. If R be then filled with water, a weight of 9820 lbs. must be placed upon the cover to prevent its being raised from its seat, *i.e.* the *same weight* as that of the column of water removed by the cutting off of the stand-pipe S at *w w*.

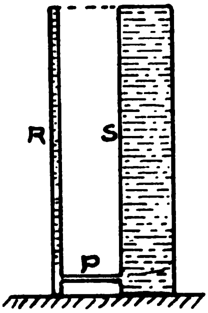


FIG. 5.

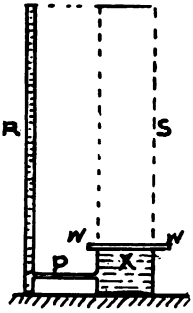


FIG. 6.

To prove this further :—The pressure due to the *height of the water column* (never mind its weight) in R is, as already seen, 21·7 lbs. per sq. in. at the bottom. The area of the large stand-pipe 24 ins. diameter = 452·3 sq. ins. Then 452·3 sq. ins. × 21·7 lbs. = 9815 lbs., total pressure tending to raise the cover plate *w w*, or practically the same as the weight of the column of water removed.

CHAPTER II

ATMOSPHERIC PRESSURE

BEFORE proceeding to the consideration of any Practical Application of the foregoing explanations, it is desirable to make some remarks relative to what is termed *Suction* of Water.

"Light as air" is a saying frequently heard repeated, signifying that the element referred to in the comparison has little or no actual weight. The comparison is, however, inexact scientifically, since the air or atmosphere has a positive weight and a not inconsiderable one.

Every portion of the Earth's surface, and all things upon it, sustain a pressure due to the weight of the atmosphere enwrapping the Globe. It was not until about the middle of the 17th century that a pupil of the great scientist Galileo, by careful and interesting experiment, clearly proved what that weight amounted to. He satisfactorily demonstrated (and subsequent inquirers fully endorsed his conclusions) that the weight of the atmosphere at the *sea level* is equal to that of a column of Mercury 30 ins. high, or that of a column of Water 34 ft. high. Thus, at sea level, the pressure of the air is about 14¾ lbs. per sq. in., but it is usually estimated in round numbers as being 15 lbs. per sq. in. Such being the case, it follows that, if a vertical pipe be inserted in a body of water so that its lower end is always kept beneath the surface, then, by withdrawing the air from the pipe, we create therein a Vacuum (or a space void of any pressure); but, as the water outside of the pipe remains subject to this atmospheric pressure of 15 lbs. per sq. in., it is forced up the pipe into the vacant space caused by the withdrawal of the air, to a height (34 ft.) at which it would balance the Atmospheric pressure, and will remain so balanced as long as the Vacuum is maintained in the pipe.

It is possible to exhaust the air, and to produce a Vacuum in the pipe to a much greater height than 34 ft., but the water will not follow it, since it can only rise to the height it is *forced* to by the pressure of the atmosphere, and that is but 15 *lbs. per sq. in.*, equal to a column of water 34 *ft. high.*

It follows that by means of a Pump, placed a certain height above the water (theoretically not exceeding 34 ft. vertically), the air can be exhausted from the Suction pipe (*i.e.* the pipe leading from the pump into the water) and the water raised into the pump barrel, there to be dealt with by Mechanical arrangements. Although, theoretically, this can be effected for a height of 34 ft., practically the limit is below this, since constructive defects, wear and tear of moving parts, etc., seldom allow of a perfect vacuum being produced to that extent.

In Actual Practice it is always desirable not to exceed 28 ft. or 30 ft. of vertical "Suction," and even if this can be reduced to 20 ft., it is better, as it affords greater certainty in the pump action.

It should, moreover, be borne in mind that, since the efficiency of Suction is dependent upon the Pressure of the Atmosphere, which pressure decreases in proportion as the location of the pump is higher than the sea-level, this elevation is a material factor to be dealt with.

The following Table of Atmospheric Pressures at various Heights will be found of service in this connection :—

	Lbs. per sq. in.		Height of. Water Column.
At sea-level pressure of atmosphere . . .	14·75	to balance	34·0 ft.
At ¼ mile above sea-level .	14·02	„	32·6 „
„ ½ „ „ „ „ .	13·33	„	31·0 „
„ ¾ „ „ „ „ .	12·66	„	29·5 „
„ 1 „ „ „ „ .	12·02	„	28·0 „
„ 1½ „ „ „ „ .	10·88	„	26·0 „

It will thus be seen that in fixing a pump at an elevation of, say, 5000 ft. above sea-level, it will not do to depend upon drawing water by suction from so great a depth as *at* sea-level by about 6 ft.

From the foregoing remarks it will be evident that the question of Efficient Suction is one of much moment in all Pumping Installations.

It should be accepted as an Axiom that the less the vertical suction, the less the liability to trouble with any Pumping appliance. A well-fitted, newly erected pump may work efficiently well with a fairly heavy suction, but as the pump bucket, or piston, wears by its friction with the pump barrel, so the efficacy of the suction power of the pump is liable to diminishment, and the longer the vertical suction, the more frequently repairs will be needed.

The *length* of Horizontal Suction pipe is largely immaterial, since no work other than that of overcoming any frictional resistance of the flow of water in the pipe is entailed thereby. It is, however, most essential in maintaining a good suction, that all joints should be perfectly air-tight, and it is always desirable to have as few of these as possible.

It will thus be understood that in estimating the Suction "duty" the vertical height of same need alone be counted as actual *work.*

Thus, if a Suction pipe be laid along a slope of any great length from the Pump to the Water, the actual "Suction" to be reckoned with is only that of the difference of level between the bottom valve of the pump and the water from which the supply is drawn.

A Suction pipe should be about two-thirds the diameter of the pump barrel in a Double-acting pump, and should always (if it is in excess of 5 or 6 ft. in length vertically) be provided with a "Foot-valve" at its lower end, which, whilst admitting water to the pipe, will prevent its return (see fig. 7), the aggregate area of the perforations in the strainer of which should be from two to two and a half times the area of the Suction pipe.

It is found that the greatest speed at which water will flow in a Suction pipe is 500 ft. per minute, but in practice the speed of flow should not exceed 200 ft. per minute to ensure a full supply.

There are few people who have not had occasion to pump water from a well by means of an ordinary "lever-handle" pump, and they will readily recognise the object-lesson thereby afforded. At the first stroke of the lever there seems to be no result; at the second or third a little resistance is felt, that is because a little air has been pumped out, and the water has risen a short distance in the suction pipe, the Vacuum pulling against the operator. At each succeeding stroke the machine gives out a different "tone," and requires less of a "pull," if there is a Foot-valve on the lower end of the Suction pipe; but, if there is *not* such a valve, then the pull becomes heavier as the water rises in the pipe, as its increasing weight is tending more and more to draw it back, "to find its own level"; this is usually termed the "pull" of the Suction.

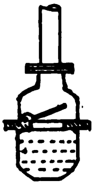


FIG. 7.

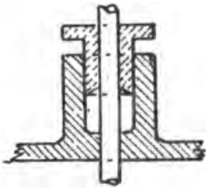


FIG. 8.

The rise of the water in the Suction pipe can be almost *felt* by the operator at the pump handle, until at length the water flows out at the pump nozzle.

A Vacuum such as that I have described can only be produced when dealing with clean fresh water. In pumping Salt water, it will be readily understood from a comparison of the relative specific gravities of Fresh and Salt water, that the latter, being heavier than the former, cannot be be raised by Suction from so great a depth. Presuming that it is possible to raise Fresh water by suction 28 ft., then it would be unsafe to depend upon raising Salt water more than about 23 ft. to 24 ft.

In dealing with any other liquid than Clear Cold Water consideration should always be carefully given to this point. Thus, in pumping up Sewage, Tar, Syrup, etc., by Suction, allowance must be made for the density of the material to be pumped, and in correspondence therewith. The more foreign matter the liquid contains, the less should be the Vertical Suction.

In pumping Warm, or Hot liquids, another important element has to be taken into account. Water boils at 212° Fahr. when under the full pressure of the Atmosphere at sea level; if any of that pressure is exhausted or removed (by artificial means, or owing to difference of level), then it would vaporise much sooner, and in direct proportions to the reduction of Atmospheric pressure, *i.e.* to the degree of Vacuum. No other proof of this is needed than the well-known fact that water will boil at the top of a high mountain (where the atmospheric pressure is less than at the sea level) at much below 212°.

If an attempt be made to create a Vacuum over Hot water, it will commence to vaporise, and such vapour will destroy the Vacuum and prevent Suction by a pump.

When liquid is very hot, it will not be found possible to raise it by Suction at all, but the pump must be so placed that the liquid will *run into* the pump barrel by gravitation, and it can then be forced to any required height.

THE SYPHON

It will not be inappropriate in connection with this subject of Pressure and Vacuum to introduce some remarks relative to the Syphon.

In any practical application this usually takes the form of the bent tube or pipe shown in fig. 9. If a piece of tube be bent into the shape shown in the illustration, with the leg B of greater length than the leg A, and then be filled with water, and the ends stopped, and it be placed with one of the legs in a vessel of water as in the figure, upon removing the stoppers the water will be found to flow out at the open end of B with a velocity proportionate to the difference in level betwixt the level of B and that of the water C C in the vessel. It will, moreover, continue to flow (but with a gradually diminishing velocity) until the water is lowered to the level of the open end of A, when air will rush through and the flow will cease. If, however, the outer leg B of the Syphon were to be prolonged (as shown in dotted lines) to B′, and the inner one to the bottom of the vessel, then (provided always that the level of the open end B′ is below that of the submerged end A′) the flow would continue until the water was quite withdrawn from the vessel.

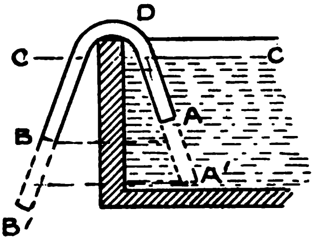


FIG. 9.

The principle upon which the Syphon acts is in full accordance with those already explained. The tube being filled with water and the stoppers removed, the water in the longer leg from B to C (C C being the level of the water in the vessel) begins to flow out with a greater velocity than that with which it rises in the shorter leg A to C, and thus tends to produce a Vacuum at the highest part of the bend D. The water in leg D A, pressed upon by the Atmosphere, rises immediately to fill this Vacuum, and thus being set in motion will continue to flow so long as the column of water in the shorter leg is less than that in the longer leg. The greater the difference in level betwixt A and C C, the more rapid will be the flow, and it will diminish in rapidity the nearer these levels approximate.

As a Natural machine the Syphon can be applied to very many useful purposes, such as emptying vessels that cannot well be overturned and have no outlet, or conveying water from one side of an elevation to the other side. It is frequently so applied in Water-works, Irrigation-works, or Drainage-works. Thus, in fig. 10, suppose it is desired to drain a Ditch or Swamp on one side of a hill F, into a River or Stream G, at a lower level on the other side:—A pipe may be laid from a drain, or catch-pit, at H, over the hill F to the River, and if all the joints be made perfectly air-tight, the water may be "syphoned" over as required. The length of the horizontal pipe at the top of the hill K being to a great extent immaterial.

In such an installation a Stop-valve would be needed at the foot of each leg, and an opening at K with an air-tight cover through which the Syphon may be charged. In Practice it is usual to place an Air chamber at K with a stop-valve, and a removable cover, arranged somewhat as in the sketch (fig. 11, A, being an Air-vessel; C, Air-tight Cover; D, Stop-valve). To charge the Syphon the cover is removed and the Stop-valve opened, and the Valves at the bottom of the Legs closed. Water is then poured in until both Legs and the Air-vessel are entirely filled. The cover is replaced and fastened down air-tight. The valve at H and that at G being now opened, the water will flow through the longer leg N. As water carries with it some amount of air, this will begin to collect at the highest point (the Air-vessel), until after a short time it will fill the Air-vessel, and, if not allowed to escape, will also fill the upper part of the bend at K, and stop the flow. When, however, the Air-vessel is full of air, the Stop-valve at D should be closed, and the cover removed to let out the air, the vessel filled with water,

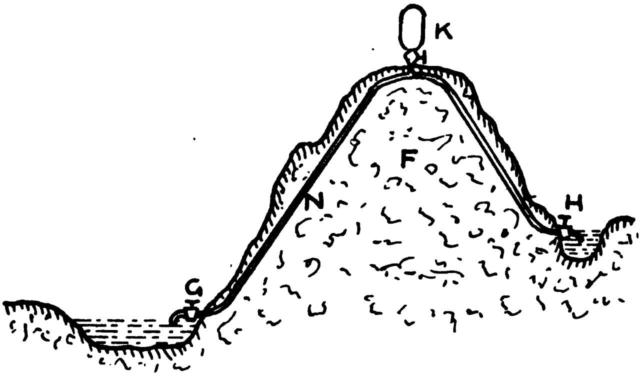


FIG. 10.

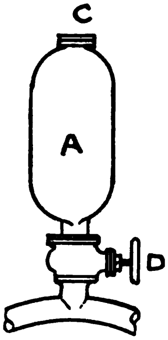


FIG. 11.

cover replaced, and valve D opened. The flow will then be maintained until air again accumulates, when the operation must be repeated. (This operation can, of course, be controlled by Automatic arrangements.)

As the action of a Syphon is dependent upon Atmospheric pressure balancing the column of water in what may be called the "Suction Leg" (D to A, fig. 9, or K to H, fig. 10), the vertical height must not exceed about 28 ft. above the lowest level of the water in the reservoir it is drawing *from*, but there is no restriction as concerns the length of the "Delivery Leg" N, provided it always exceeds the *Vertical* length of the Suction side of the Syphon.

WATER FLOWING BY GRAVITATION

Before proceeding to the consideration of raising, or forcing water by Mechanical Appliances, it will be well to devote a little attention to some points affecting the behaviour of liquids when flowing through pipes by Gravitation only.

Foregoing remarks have dealt, chiefly, with questions affecting water at Rest, or when flowing into a Vacuum, but there are some other conditions obtaining with Flowing Water, which may be briefly referred to.

It has been explained that a column of water when confined in a pipe, or a vessel, exerts a pressure at its base equal to ·434 lb. per sq. in. for every foot of height of the column, and so long as the water remains at rest, this is maintained. If, however, some outlet be made at the lower part of the containing vessel, allowing a Jet of water to escape, whilst sufficient water still enters the top of the vessel to keep it full, it will then be found that a diminution of pressure occurs at the bottom part of the vessel proportionate to the Velocity of the escaping Jet. To illustrate this, suppose two vessels M and N, fig. 12, connected together at their lower ends, be filled with water to the level O O′. If the tap at P be opened to allow a jet of water to escape, at the same time that water is allowed to flow into the vessel at the top, in sufficient quantity to maintain the level at O in M, it will be found that this level will not be maintained in the vessel N, but will sink below the level of O′, to a determinate distance according to the force of the jet issuing from P. If this outflow did ***not*** diminish the pressure due to the "head" of water in M, then the level of the water in N would have remained undisturbed, since by keeping the vessel M constantly full to the level O, the same "head" has been maintained. In order to define the cause of this fall of pressure, it is essential to offer some further explanation of that which constitutes what is termed a Head of Water. It embraces three divisions, viz.:—

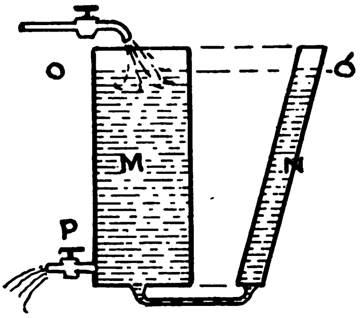


FIG. 12.

1. The "*Entry Head*," required to overcome such resistance as may occur through the passing of the water into the outlet pipe, due to eddies set up consequent upon change of direction of pressures.

2. The "*Friction Head*," required to overcome the retarding effect of the Attrition of the moving water against the sides of the vessel.

3. The "*Velocity Head*," or the head required to give to the water the energy needed to maintain a uniform velocity of flow from the containing reservoir.

At present it need only be pointed out that the influence of the "*Entry*" and "*Frictional*" resistances in above, being factors in the effect which would otherwise be produced by the *full* pressure of the column of water in M, fig. 12, are responsible for the lowering of the level of the water in N, and that the measure of these effects cannot be ascertained apart from the question of the Velocity of the issuing Jet at P.

It is necessary here to more fully consider the term "Velocity," as applied to "Hydraulics." It is incidental to the Law of Falling Bodies (that is, bodies descending by force of Gravitation from any Height to a Lower elevation). Thus water, in common with solids, acquires velocity whilst falling through a certain distance, and the measure of this velocity is expressed in the formula

$$V = \sqrt{H} \times 8.$$

V being the velocity in feet per second.
H being the height in feet through which it falls.

Table IX. gives the Velocities for various Heads as derived from this formula. As these Velocities refer to substances falling "in vacuo" (or unopposed by extraneous influences), they are termed "Theoretical Velocities," and, of course, require modifying according to conditions when used in reference to the flow of water in pipes or vessels.

Now, since the velocity of water is dependent upon the height of its "Head" above the issuing point (as P, in fig. 12), it is obvious that the greater the "head" of water in, say, a reservoir as M, the larger the quantity it would deliver through a certain size of pipe P.

The Theoretical Discharge, in Gallons per Minute, through a certain size of pipe under a given "Head" may be found by the formula

$$G = \sqrt{H} \times D^2 \times 16{\cdot}3.$$

G being gallons discharged per minute.
D being diameter of pipe in inches.

It should be here noted that the "Velocity Head" remains the same for any length of pipe (as at P), being merely dependent upon the "Velocity" of the water in the pipe.

The "Entry Head" may be ordinarily assumed to be about *one-half* the "Velocity Head."

Having dealt with the questions of "Entry Head" and "Velocity Head," that of "*Friction Head*" may now claim attention. This is a factor of very great importance in all considerations relative to Flowing Water, and in this connection of water passing through vessels and pipes by Gravitation, it must be dealt with as a modification of the results of any calculations under the foregoing Rules.

Having ascertained the Theoretical quantity of discharge, it is requisite to find the amount of the Friction to be overcome, in terms of a certain additional "Head," to those already due to "Entry" and "Velocity."

The formula for this is

$$H=\frac{G^2\times L}{(3^d)^5}$$

or, to put it into words, the "Friction Head" (H) is equal to the square of the number of gallons *per minute* (G^2), multiplied by the length of the pipe *in yards* (L), and this sum divided by the "fifth power" of three times the diameter of the pipe in inches $(3^d)^5$ = head due to Friction.

The resultant (H) represents the loss of Efficient "Head," or, in other words, the "head" that must be added to that of "Velocity" and "Entry" to ensure a full flow as per "Theoretical Discharge" referred to above.

Returning now to the question of the variation in the levels of the water in the two vessels M and N, fig. 12, this difference in level will be found to amount to the total of the "Heads" required to overcome the resistances due to "Entry" and "Velocity" added to the Friction of the water in the vessel M, whilst descending from the level at O to that of the discharge orifice at P.

Although now referring to water flowing by "Gravitation" (as will be more definitely explained later on), the formula given above in relation to "Friction" applies in like manner to Pumping work, the "Friction Head" then representing a resistance, to be dealt with by the Pumping power.

"HYDRAULIC MEAN GRADE"

The above-mentioned components of the total "Head" are also factors in the production of certain effects in long lengths of pipes incidental to what is known ordinarily as the "Hydraulic Grade Line" of water flowing by Gravitation. Although the matter does not materially influence Pumping operations, it is so far kindred to the subject as to demand some little consideration.

Suppose fig. 13 to represent a long length of Pipe main, *a a a a a*, following the contour of the ground, and having its outlet at X, which main is kept supplied from a Tank or elevated Reservoir. A number of Vertical Pipes, open at their upper ends, and marked A B C D E F, are presumed to be situated upon, and connected with, the said Pipe line. If the outlet at X be closed, the water will come to rest in the Pipe line and in the Vertical pipes, at a uniform level throughout, coinciding with the Level of the Water in the Reservoir, and would so remain so long as no Flow took place.

Suppose the outlet at X to be then opened, allowing the full flow of the water from the Reservoir, it will be found that the water level in the Vertical pipes will be progressively lowered all along the length of the System, and will assume a level indicated at each Stand pipe by a line drawn from the Friction Head level in the Reservoir (say at O) to the opening at X, this Imaginary line constituting the "Hydraulic Grade Line" in this example.

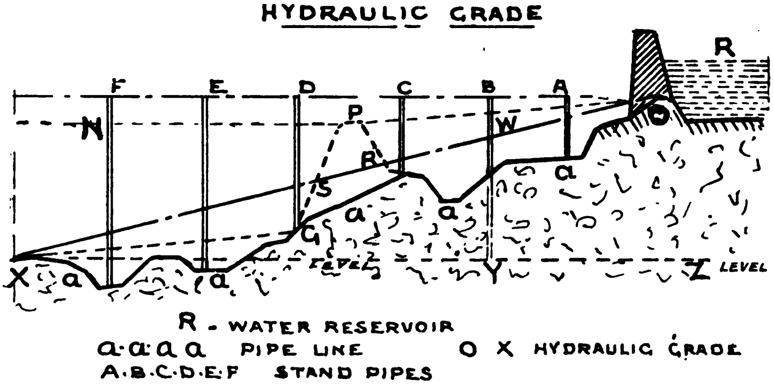


FIG. 13.

It would also be found in practice that these levels in the "Stand Pipes" (if the Main pipe were of uniform diameter throughout) would not be materially affected by vertical sinuosities in the Main pipe, neither would any loss of Useful effect occur thereby, always provided that it did not at any point rise *above* the level of the Grade line O X.

Let it be assumed, however, that between C and D of the Vertical pipes the Main pipe rises to P (a point above the Grade line O X) and then falls to G, the position of things is altered, and that portion of the pipe between the points R and S will be liable to an accumulation of air as in a Syphon (which, indeed, that part of the pipe R P S becomes). Any *effective* "Head" between P and S is lost; Hydraulic Grade now being from O to P (as shown in dotted lines), then dropping to G, and thence (parallel with O P) from G to X.

The water descending by Gravity from P to G would have a greater velocity (due to its Head P to G) than that due to any fall or Head between O and P, so that the pipes from P to X would only be partially filled.

Instead of the pipe being of a uniform diameter throughout, that part between O and P (following, of course, the Ground Contour) should be larger than that betwixt P and X, in order that it should (with the Head due to vertical height between F and N) supply sufficient flow to fill the pipes from P to X, which would have a Head equal to N to X.

It may also be noted that (supposing the Figure were drawn to scale) any vertical distance from Grade line O X to horizontal line X Z will give the Friction head between W and B.

It should be understood from the foregoing remarks that, under the conditions referred to, the "Effective Head" of Pressure to deliver Water from O to X would resolve itself only to that due to the Head (vertically only) between the horizontal line A to F and the highest point P of the Pipe line.

Many vital and interesting points arise in connection with this matter of Hydraulic Grade, and anyone interested in laying long lines of Pipes over irregular ground should pursue the subject more fully than its connection with the Elementary views of this present work would warrant.

In all questions of Water Supply it is indeed a necessity that a study should be made of this particular subject.

CHAPTER III

PUMPING WORK

FROM foregoing explanations it will be understood that in Pumping or Forcing Water, or other Liquids, to an elevation above the level of the Mechanical appliance used for the purpose, the opposing influences are:—

1. The pressure of the water due to its "Head" consequent upon the *Vertical height* of the column of water to be moved, which pressure equals ·434 *of a pound* upon every square inch of the impulsive surface, for every foot of *Vertical* height of column, *irrespective* of the area of the column itself.

2. The additional pressure due to the *Friction Head*, which varies according to the *area* and *length* of the pipes, and the Velocity of the water passing through it.

3. The *Inertia* of the mass of water contained in the pipes, which amounts to the *weight* of a cylindrical column of water, of the area of the impulsive surface (presumably a Pump Bucket, or Piston), and of a height equal to the *vertical* distance of the Motive power from the point of delivery. This Inertia must be overcome in order to keep the column of water in motion.

It may be taken for granted that it is quite immaterial, so far as the first and third items are concerned, whether the delivery main is *Vertical*, or has an indefinite *Inclined* length. The Resistances in these relations are estimated upon the Vertical distance, since this alone defines the distance the liquid has to be Lifted or Forced.

As concerns the second item, the element of the length of

Main pipe has an important bearing upon the work entailed, since Frictional resistance to the motion of the liquid occurs throughout the *entire length* of the pipe line.

These points being duly borne in mind, an advance may now be made to the consideration of the best Mechanical arrangements for meeting the Conditions.

It is not proposed to attempt any detailed description of the Mechanism of the numerous varieties of Pumps (since they are as multifarious as the purpose to which they are applicable), but more particularly to set forth the conditions that should govern the selection of the class of Pumping apparatus for any Special purpose, and the points which should be studied, when deciding upon the size to be adopted, and its most favourable Installation.

Hand-pumps (or pumps worked by Manual power) may first claim attention. Of this class the "Barrel Pump," with reciprocating bucket, or piston, is the most largely used. These may be "Single-acting" or "Double-acting," "Vertical" or "Horizontal."

A "Single-acting" Pump requires to make an In-stroke, and also an Out-stroke, to deliver one charge of liquid; consequently, the flow is *intermittent.*

A "Double-acting" Pump, or a two-barrel pump, on the other hand, delivers a charge of liquid at each in-stroke and each out-stroke, thus making the flow approximately *continuous.* Or this result of continuous flow may be attained by means of what is known as a "Bucket and Plunger," or a "Piston and Plunger" pump, which discharges one-half of the contents of the pump at each in-stroke, and one-half at each out-stroke, in a continuous flow. A Pump may be either a Lift Pump, raising the water by "Suction" to the Pump barrel, and there discharging, or it may be a "Lift and Force" pump, raising water by Suction to the level of the pump, and thence forcing it through suitable pipes to any required height above that level. And in this connection it should be noted that all those parts which are below the level of the Pump bucket or Piston come under the head of "Suction."

It is frequently found desirable to group two pumps together side by side, so arranged that both draw from the same Suction pipe, and deliver into the same "rising main" or "delivery pipe."

As such pumps are usually worked through the medium of Connecting-rods, operated by a Rotating shaft, the Cranks are so arranged that one pump bucket is on the in-stroke, whilst the other is on the out-stroke. Then, although each barrel may be single-acting, they jointly produce a continuous flow, equivalent to the action of a Single-barrel double-acting pump. Or three Pump barrels may be grouped together in this way, giving conjointly a very steady delivery. If Double-acting Pumps are so grouped, they give most desirable results in steadiness of delivery and freedom from shocks.

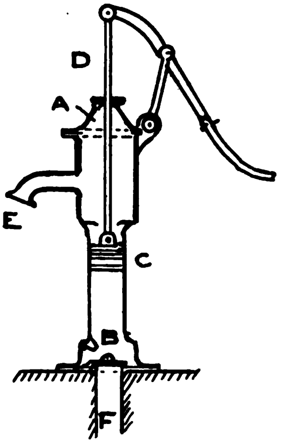


FIG. 14.

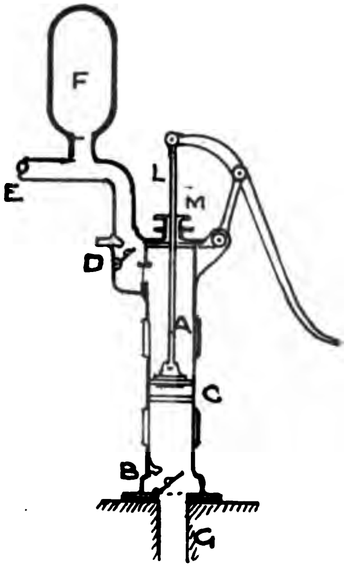


FIG. 15

The sketches given in annexed figures will assist in more clearly demonstrating the several arrangements of Single- and Double-acting Pumps.

Fig. 14 shows a common "Lift Pump" with Lever handle. A, is the Pump barrel; B, the Suction valve; C, the Pump bucket or Piston, with valve opening upwards; D, the Pump rod; E, the Nozzle; F, the Suction pipe.

Fig. 15 illustrates the arrangement of a common "Lift and Force" Pump, Single-acting. A, Pump barrel; B, Suction valve; C, Pump bucket and valve; D, Delivery valve; E, Delivery pipe; F, Air vessel; G, Suction pipe; L, Pump rod; M, Pump cover and gland or "Stuffing-box," in which the rod works water-tight.

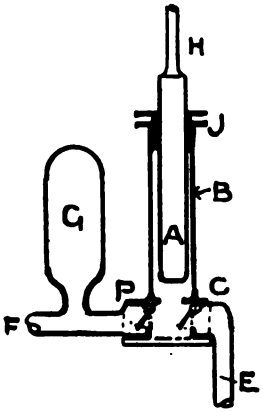


FIG. 16.

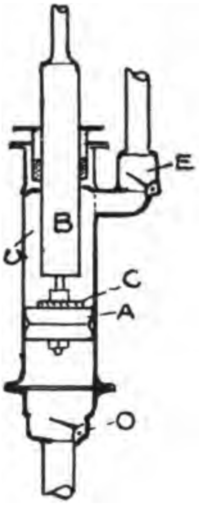


FIG. 17.

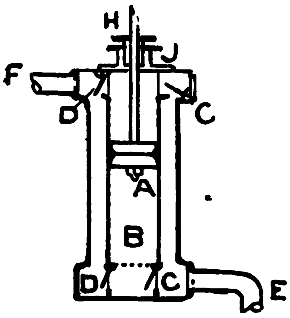


FIG. 18.

Fig. 16 shows a "Lift and Force" Pump of the "Plunger" type, also Single-acting. A, Pump plunger; B, Pump barrel; C, Suction valve; D, Delivery valve; E, Suction pipe; F, Delivery pipe; G, Air vessel; H, Pump rod; J, Pump gland.

Fig. 17 is a sketch of a "Bucket and Plunger" Lift and Force Pump, in which A is the Bucket; B is the Plunger; C, the Bucket valve; D, the Suction valve; E, the Delivery valve; the area of A being twice that of the plunger B, and the area of the annular space G one-half the area of pump bucket.

Fig. 18 represents a "Double-acting" "Lift and Force" Pump. A, Pump bucket; B, Pump barrel; C C, Suction valves; D D, Delivery valves; E, Suction pipe; F, Delivery pipe; H, Pump rod; J, Pump gland.

FOOT-VALVE.

The object in making use of a Foot-valve on the Suction pipe is to retain the liquid in the pipe, but when the vertical length of the pipe is short, and direct, it may be dispensed with, since the labour involved in exhausting the Air and raising the liquid to the pump each time it is used does not amount to much. If there should be any considerable length of Suction, however, the air has to be exhausted throughout its entire length, before the liquid can be raised, every time the pump is used. When the Vertical Suction exceeds about 12 ft., the Foot-valve should be used in all cases, and the reason is obvious; it is only on the up-stroke of the Single-acting pump that the air is exhausted, and during the time occupied in the Down-stroke the liquid already raised in the Suction pipe is liable to slip back to its "lowest level," such liability being the greater in proportion to the height it is raised in the Suction pipe, but the Foot-valve *keeps* what is gained at each stroke, and, if properly fitted, retains the pipe full of liquid ready for use at the next stroke.

AIR VESSELS.

In all "Lift and Force" pumps, the use of an Air Vessel is strongly advocated. It is simply a hollow vessel of elongated shape (usually with a height of two or three times its diameter for Small pumps, although there is no particular rule for size or capacity), placed vertically on, or in connection with, the Delivery pipe near to the pump, with a free opening from the pipes. Its function is to act as an air cushion or spring, since the air contained in the vessel is compressed in its upper part during any forcing action of the Pump, or Pumps, when such action is checked by the reversal of the pump stroke, the resulting Elasticity acts upon the liquid Column as a Spring, and tends to keep it in motion pending further forcing action of the Pumps, and thus equalises the flow of liquid and obviates shocks in the pipes.

In Single-acting Pumps especially, the Air Vessel is a most useful adjunct, as the motion imparted to the water in the Delivery pipes by the forward stroke of the Pump piston is stopped entirely whilst it makes its back-stroke; consequently, on the next forward stroke the inertia of the water column has again to be overcome, and the force required for this is much in excess of that needed to keep up the flow had it not been interrupted. The spring-like action of the compressed air in the Air Vessel in giving out its stored-up energy helps to overcome the inertia of the liquid and thus aids the action of the Pump. In Double-acting pumps the delivery is steadier, but still an Air Vessel is desirable, as it obviates shocks in the pipes, and eases the action of the Pump valves.

For "Double-acting" pumps the following proportions of Air Vessel are suitable:—

For Pumps with

1 Barrel or Cylinder.	Volume of water delivered at each stroke.	×	Pressure of column in lbs. per sq. in.	× ·100
2 do.	do.		do.	× ·055
3 do.	do.		do.	× ·025

The resultant in each case = Capacity of Air Vessel.

The usual methods of attachment of Air Vessels are illustrated at figs. 19 and 20, in which A A, A A represent the Delivery pipes, B B the Air Vessels. When arranged as in fig. 19, the delivery pipe above the Air Vessel enters to a depth of about two-thirds the length of the vessel. When the pump is in action water enters the Air Vessel to a point above the opening to the Delivery pipe at F, and prevents the access of more air to the vessel, whilst the forcing action of the Pump compresses that already stored in its upper part, thus forming the spring, or elastic medium, required. If placed as in fig. 20, a similar effect is produced by the compression of the air in the upper part of the Air Vessel.

A Cock for the admission of air, when needed, should be fixed at the upper part of the vessels, since a renewal of the air supply is requisite from time to time. The passing liquid absorbs the air at a rate dependent upon the pressure to which it is subjected. In many cases (such as when pumping from very deep Mine shafts), an Air Vessel has little virtue on account of this liability to the absorption of the air by the Water column.

Similar Vessels, especially in the case of large Pumps, or where there is a long length of pipe, are frequently attached to the Suction pipes near to the Pump, and are then termed "Vacuum Vessels," being designed to maintain a more powerful vacuum in the suction, by an opposite effect to that of a vessel on the delivery. Air should not be admitted to a Vacuum Vessel when the pumps are in action, since it is intended that the vessel should be utilised as a vacuum storage instead of a reservoir of compressed air. A "Vacuum Vessel" should have the effect of a spring in Tension, an "Air Vessel" that of a spring in Compression.

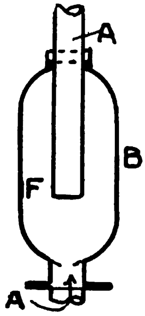


Fig. 19.

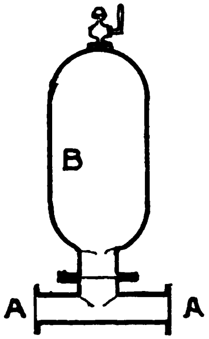


Fig. 20.

The Author has frequently been called upon in the course of practice to advise as to the best method of preventing undue jarring and heavy working of Pump valves, especially in connection with High-Lift pumps. Although it is found that well-proportioned Air Vessels do much to obviate this trouble, they do not always entirely prevent it. It is, however, found that few cases will not yield to the application of a small "Snifting valve," placed upon the Suction pipe near to the Pump. This Valve is so constructed that at each suction stroke of the pump a small "snift" of air is allowed admission into the Suction pipe, and slightly aerates the water, making it more elastic and thereby easing the pump valve.

The decision as to the particular class of Pump to be used for certain work should be governed by such considerations as those enumerated below :—

Is the work entailed heavier than would justify the use of Hand (or Manual) power? If not, can a common Lever-handle pump be used, or must rotary gear be used?

If Motive power must be resorted to, what kind shall be adopted? Animal power, Wind, Water, Electricity, Gas, Oil, or Steam power?

As local conditions must of necessity influence this point, it is not possible to give any actual rules thereupon. It may, however, be generally accepted that, when the quantity required to be dealt with is but moderate, and can be raised in one or two hours daily, Hand-worked or Animal-driven pumping apparatus will be the least costly. Under any circumstances, the following data should be obtained before any decision is arrived at:—

1. What Quantity of Water has to be dealt with per day or per hour?

2. What is the vertical distance from the position the Pump will have to occupy to the water level in the well, reservoir, or receptacle from which the liquid has to be drawn?

3. What is the standing depth of the water in same?

4. What is the horizontal distance from the supply to the pump site?

5. To what height has the liquid to be forced above the site of the pump?

6. What horizontal distance has it to be forced?

7. Is the liquid clean, or is it thick or foul and gritty?

It will be best to take up the consideration of each of these points in the order in which they are given above, and to bear in mind that the remarks made upon each are generally applicable to all kinds of pumping apparatus.

First.—The quantity of water which has to be dealt with per day or per hour.

It should be well considered whether this should require continuous pumping for the whole day, or if it be not most economical under the particular circumstances to confine the work to a few hours daily. Although this might necessitate somewhat more powerful and more expensive plant than would be needed were the work spread over a greater period of time, other items, such as saving time in attendance, shorter period of wear and tear of machinery, economy in fuel, etc., would possibly make it desirable. A decision should thus be arrived at as to the quantity of liquid to be dealt with *per hour.*

In cases where a considerable quantity of Water on the surface is available, with an eligible position at hand for placing a Pumping apparatus, it may be possible to utilise some portion of such supply in pumping a smaller portion to a higher elevation by means of a "Water-Ram," "Turbine," or "Waterwheel," and as such apparatus is well-nigh Automatic, advantages offer which make such adaptation very desirable.

Later on it is proposed to offer some remarks in reference to such Water-moved machines, but at present it is intended to deal with those agencies I have previously enumerated.

Second.—The consideration as to the most favourable position for the Pump in relation to the Source from which it has to draw the water is a most important one. It may be assumed that the nearer it can be placed vertically and horizontally to the Supply the better it will be. Whatever may be the selected or enforced position of the Motive power, the pump barrel, or barrels, at any rate, should be placed within a vertical distance of not more than 25 ft. from the Water level, and preferably not more than 20 feet. Although (as already explained under the heading of "Suction") it is theoretically possible to draw water by suction from a depth of 32 ft., it is not practically so, owing to possible defects in pumping appliance, and to liability to wear and tear of the suction portion of the apparatus.

Third.—The greater the length of Suction pipe used the greater the chance of leakage therein; therefore, the shorter it can be made the better in all respects.

If it is essential that the motor should be at the top of the well or shaft, whilst the pumps have to be placed below, the motive power must be conveyed through the agency of shafting, belting, and pump rods, or other appliances, the pumps being fixed upon staging fitted up in the well or shaft. In case a Direct-acting Steam pump is used, it can, if desired, be placed in the well within, say, 20 ft. of the water, and the steam conveyed to it through well-protected pipes. Or, as in case of Shaft sinking, the steam pump is frequently placed upon a staging, slung by chains from the top of the shaft, in such a manner that as the sinking proceeds additional length of steam pipe and delivery pipe can be added as the Pump is lowered.

In using the "Cornish" type of pump, in which the pumps are placed down a Shaft and worked by rods operated from the surface, the power may be conveyed to the Shaft by Rocking-levers and Rods, should the engine be at a distance away from the Shaft.

The various methods of conveying the Power from the Motor to the top of the Shaft, or Well, are, however, so numerous that they cannot be detailed within the limits of such a Work as the present.

To return to the question of "Suction pipes." The area of a Suction pipe should, in any case, be not less than two-thirds of the area (or combined areas, if more than one pump draws from it) of the pump piston or "bucket," and great care should be taken to make the joints in such pipe perfectly air-tight. As already explained, if the vertical suction exceeds, say, 5 or 6 ft. in length, a "Foot-valve" (fig. 7) should be attached to its lower end, and this should be provided with a strainer to prevent the ingress of any foreign matter to the Suction pipe.

Fourth.—Should the Horizontal length of Suction pipe be considerable, it should be laid with some small *upward* inclination towards the Pump, and it certainly must not, at any point of its course, rise to a higher level than the bottom of the pump, since air would be liable to accumulate in any such elevated part and spoil the suction power of the pump. It is also advisable that a Suction vessel should be used in the case of a great length of Suction pipe.

Fifth.—The height to which the water has to be delivered vertically above the position of the Pump barrel should be accurately ascertained, as upon that item principally depends the proportioning of the requisite ratio of Motive power to pump capacity for operating the Pump.

Sixth.—The Horizontal length of Delivery pipe required in this connection is not so material, provided due attention is given to so proportioning its area as to avoid any excess of work being entailed, by having to unduly *force* the water through the pipes.

A certain amount of Friction is caused by the flow of the Water through the pipes, and the amount of such Friction (dependent upon the area of the pipes themselves) is an ascertainable quantity, diminishing in a fixed ratio as the area of the pipes is increased.

The sum of Frictional resistance, termed "Friction head," being reduced by calculation to an equivalent "Head," should be added to the Vertical height of the delivery and the suction (since work is expended in drawing the water to the Pump in the same proportion as in forcing it to its destination). (The Table No. IV. will assist in the calculations here required.)

If the total "Head" in feet thus ascertained be multiplied by ·434, or by the fraction $\frac{3}{7}$, it will give the pressure in lbs. per sq. in. which will form the "Load" upon the pump, since the pressure due to a column of water is, as explained previously, in the proportion of, approximately, 3 lbs. per sq. in. for every 7 ft. of vertical height, or more accurately—

Total "Head" × ·434 × Area of Pump bucket = number of lbs. weight to be raised.

Respecting the Class of Pipes that should be adopted, it is undesirable to use cast-iron Socket pipes in the case of "delivery," if the pressure per square inch exceeds about 100 lbs. The joints have to be made with some description of Packing, and there is always a liability to having this packing forced out and causing leakage. In "Suction pipes" Socket piping should not be used at all if avoidable, as the weight of the pipes themselves tends (however well they be supported) to drag the joints apart. Flanged pipes—if the joints be made with india-rubber packing rings—offer much greater security. Where wrought-iron pipes are used, the unions should be securely sealed with red-lead and tow.

It must be remembered that any leakage in the Suction pipe seriously cripples the efficiency of the Pump, whilst in the Delivery it means a waste of power proportionate to the "Head" of water above the leak.

CHAPTER IV

FRICTION OF WATER

In the foregoing pages frequent mention has been made of the Friction of water in Pipes, and, as it is a matter very directly, and importantly, bearing upon all questions of Pumping work, as well as the ordinary Flow of water, it should now engage fuller attention.

Water in motion, whether in pipes or open channels, of necessity meets with resistance, in a greater or less degree, from its Attrition with the surface of the conduit through which it is conveyed; and, moreover, the amount of this attrition (which is termed " Friction ") *increases* in proportion to the *velocity* of the liquid passing over these surfaces.

It follows that, in allowing a given Quantity of water to flow through a pipe, if the pipe is of small diameter, the rate of flow would be less than it would be in one of greater diameter, owing to this item of Friction.

The error of employing pipes of an area *too small* for the duty is a common one, but it is far from being an uncommon one to use pipes *unnecessarily large.* Of the two evils the former is undoubtedly the *greater.*

If the question be fully considered, it will be found that a very small increase in the area of the pipes will have a *great effect* in reducing the amount of Friction.

Many designers and users of Pumping appliances, etc., rush to an opposite extreme, and put in pipes of so large a diameter as to make the friction practically nil. Now this is not always true economy, since in a long line of Pipes any increase in the size adds very materially to the cost of the installation, not only in respect to the pipes, but in enlarged excavation and increased expense of joints, etc.

It is generally the best economy to strike a medium, and employ pipes of such diameter that the amount of Friction would be but moderate, enough perhaps to necessitate the employment of a little extra power in the Pump, but not sufficient to be a very material Item. In this way the cost of the pipes may be greatly reduced below what they would be if of sufficient size to make the friction absolutely *nil.*

In deciding upon the Size of Pipes to be used in any particular Installation of Hydraulic work, it should not be lost sight of that allowance ought to be made for possible unevenness of bore and incrustation of the metal. Hence, even under fair conditions, such as well-made and well-laid pipes, and cleanliness of the water to be pumped, etc., it is best to use pipes of such size that they would discharge, say, 20 per cent. more than the desired quantity of water. When the pipes are not of First-class make, or if the water is very Foul, such margin should be increased accordingly.

The evils of Incrustation may be largely avoided by having the pipes treated internally by the "Bower-Barff," or "Angus Smith," or other process before laying them.

Tables are obtainable which will give the Data for Frictional Resistance in nearly all cases that can arise, but, as these are not always at hand, the Formula already given at page 18 should be used, viz.:

$H=\frac{G^2\times L}{(3^d)^5}$, or in words, multiply the quantity in gallons per minute by *itself*, and by the length of the pipe in *yards*, and divide the product by three times the diameter of the pipe in inches raised to the fifth power = the "Head" of water due to Friction.

Explanation of Formula.—G^2 signifies the square of G, that is, the number of gallons multiplied by the same number of gallons. Thus the square of 50 gallons is $50\times 50=2500$.

$(3^d)^5$ signifies the ***fifth power*** of ***three times*** the ***pipe diameter.*** Thus, for 3-in. diameter pipe, $3^d = 3 \times 3 = 9$.

Square.	Cube.	Fourth power.	Fifth power.
$9 \times 9 = 81$.	$81 \times 9 = 729$.	$729 \times 9 = 6561$.	$6561 \times 9 = 59{,}049$.

Example.—What will be the Head due to Friction in passing 100 gals. per minute through 600 *yds.* of 4-in. diameter pipe?

$$100 \times 100 = 10{,}000 \qquad 10{,}000 \times 600 = 6{,}000{,}000$$

$$4 \times 3 = 12, \text{ and } 12^5 = 248{,}832.$$

$$\text{Then} \quad \frac{6{,}000{,}000}{248{,}832} = 24 \text{ ft.} = \text{the Head due to Friction.}^{[1]}$$

Thus the Friction in pumping 6000 gals. of water per hour through 600 yds. of 4-in. diameter pipe = 24 ft. Head.

If 6-in. pipe be used, the Friction would amount to only 3·17 ft. head. The difference in weight betwixt 600 yds. of 4 in.-pipe and the same length of 6-in. pipe would be about 280 cwts., and at, say, 10s. per cwt., it would be about £140 in extra cost for the 6-in. pipe. Query, Would it not, in such case, be best to use the 4-in. pipe, and put a little extra work (it would only amount to 10½ lbs. per sq. in.) on the Pumping Apparatus?

As evidencing how rapidly Friction decreases in proportion to the size of the pipes:—

100 gals. of water per minute	Friction head in feet per each yard of length.
through 2-in. diameter pipes would give	1·28
„ 3-in. „ „ „ „	·169
„ 4-in. „ „ „ „	·0401
„ 5-in. „ „ „ „	·00529

The following rules will be found useful:—

To ascertain the Weight of water in pipes of any diameter—

$$\left.\begin{array}{c}\text{Square the diameter}\\ \text{in inches}\end{array}\right\} \times \cdot 341 = \left\{\begin{array}{c}\text{Weight in lbs. per}\\ \text{foot in depth.}\end{array}\right.$$

---

[1] Note that this calculation may be much simplified by the use of Logarithms.

Other very useful formulæ in connection with our subject may be found in Box's *Practical Hydraulics* (Spon).

To ascertain the Pressure of water at various depths—

$$\frac{\text{Head of water in feet} \times 62{\cdot}5}{144} = \text{Pressure in lbs. per sq. in.}$$

To ascertain the pressure exerted by a column of water of any Height upon a given area—

$$\left.\begin{matrix}\text{Feet in height}\\ \text{of column}\end{matrix}\right\} \times \text{Area in sq. in.} \times {\cdot}434 = \left\{\begin{matrix}\text{Pressure in lbs.}\\ \text{per sq. in.}\end{matrix}\right.$$

$$\left.\begin{matrix}\text{Feet in height}\\ \text{of column}\end{matrix}\right\} \times \text{Area in cyld. in.} \times {\cdot}341 = \left\{\begin{matrix}\text{Pressure in lbs.}\\ \text{per cyld. in.}\end{matrix}\right.$$

TABLE OF THICKNESS OF CAST-IRON PIPES

Diameter of pipe in ins.	Head of Water in Feet.							
	50	100	150	200	300	400	500	600
4 inches	·32	·34	·36	·38	·42	·46	·50	·54
6 "	·33	·36	·39	·42	·48	·54	·60	·67
9 "	·34	·39	·42	·48	·57	·66	·76	·85
12 "	·36	·42	·48	·54	·66	·78	·91	1·03

Note that these thicknesses are suited for Pipes connected to a Pumping system.

To find the weight of Ordinary Cast-iron Flange-pipe—Subtract the square of the Inside diameter from the square of Outside diameter, and multiply by 7·35 = weight of 1 yd. of pipe. The weight of two flanges = about 1 ft. of pipe.

In Pumping Operations, no matter what precautions may be taken (such as use of Air Vessels, etc.), there usually arises in the delivery pipes a certain amount of "Throb," or "Pulsation," due to the action of the Pumps, which in many cases should not be neglected.

CHAPTER V

UNITS OF WORK

IT should be explained that the generally accepted "Unit of Work," or standard for the Measurement of Work, is *one pound weight* raised *one foot high*; or one pound forced in any direction through a space of one vertical foot. The "*Unit*" *Rate* of Work, or the amount of work done in a given time = *One Foot Pound*, as above, *per minute.*

It is estimated that a man working a Pumping gear, or Hand pump, will do so at the rate of 3000 *Units of work per minute* inclusive of periods of rest (approximately $\frac{1}{10}$ of a H.P.).

That a Horse will perform about 22,000 *Units of work per minute* when working a Pumping apparatus.

The Power of a Steam-engine, or a Water motor, is estimated at 33,000 Units of work per minute (and will be referred to hereafter as H.P.).

In all cases, however, allowance of 25 per cent. to 50 per cent. must be made for the Friction of the Machinery, which will of necessity vary according to its simplicity and workmanship. So that, if it is ascertained how many Units of work have to be performed per minute (*i.e.* the number of pounds to be raised per minute multiplied by the height in feet, to which they have to be raised), then

$$\frac{\text{Units of work}}{3000} = \text{No. of men's power required.}$$

$$\frac{\text{Units of work}}{22{,}000} = \text{No. of horses required.}$$

$$\frac{\text{Units of work}}{33{,}000} = \text{H.P. required if steam power is used.}$$

But allowance must in each case be made for Friction (as already pointed out) according to the Apparatus employed.

If it is decided to use Man power, it can be best applied through the medium of a Rotary gear, the length of the arm of which should not exceed about 18 ins. (which would give a circle of 9·42 ft).

It is found that a Labourer can exert a force of about 20 lbs. in working a fairly well-fitted gear, at a rate of 16 revolutions per minute, which would give:—

9·42 × 20 × 16 = 3014·4 Units of work per minute.

As, however, a Man's power cannot be continuously exerted for any great length of time, about ⅕ (or 20 per cent.) of this should be deducted for periods of "rest," which would give, say, 2400 Units of work per minute, which would equal:—

12 gallons pumped 20 ft. high per minute
or 20 ,, ,, 12 ,, ,, ,,
or 60 ,, ,, 4 ,, ,, ,,
or 4 ,, ,, 60 ,, ,, ,,
or other Equivalents.

If the Work to be done is found to exceed the power of two men, it may be taken for granted that under ordinary circumstances it will prove more economical and convenient to employ other motive power.

The decision as to what Character of power to use must be generally based upon the surroundings of the Work, since the most advantageous power in one place, or under a certain set of conditions, might prove the most costly in another.

Gears worked by Horses, Mules, or Bullocks may be best in some situations.

Wind power is very extensively used in many localities as a Motor, but, of course, has the disadvantage of not being at all times available. This it may be possible in many cases to compensate by providing a sufficient Storage.

Water power, even to Pump water, may under many circumstances be the best suited to the conditions, and may be utilised through the agency of Waterwheels, Turbines, Hydraulic Rams, etc.

When, however, it is a question of dealing with large Quantities of water, and especially if it has to be delivered to any great height, it will probably be most convenient and economical to use Pumps driven by Compressed Air, Gas or Oil Engines, or Electricity.

In estimating pumping power the following rules may prove serviceable:—

To ascertain the Units of Work in raising *a given quantity of Water*—

$$\left.\begin{array}{l}\text{Gallons per}\\ \text{hour to be}\\ \text{raised}\end{array}\right\} \times \overset{\text{lbs.}}{10} \times \left\{\begin{array}{l}\text{Height in feet}\\ \text{to which it has}\\ \text{to be raised}\end{array}\right\} = \text{Units of Work.}$$

To calculate the Quantity of water a pump *will deliver per hour.*

This will, of course, depend upon the diameter of the Pump barrel and the speed at which the pump is worked. This latter item should be resolved into what is termed the "Velocity" of the Pump, and is ascertained thus:—

Single-acting Pump—

$$\left.\begin{array}{c}\text{No. of strokes}\\ \text{per minute}\end{array}\right\} \times \left\{\begin{array}{c}\text{Length of stroke}\\ \text{in inches}\end{array}\right\} = \text{Velocity per minute.}$$

Double-acting Pump—

$$\left.\begin{array}{c}\text{Twice the No. of}\\ \text{strokes per minute}\end{array}\right\} \times \left\{\begin{array}{c}\text{Length of stroke}\\ \text{in inches}\end{array}\right\} = \left\{\begin{array}{c}\text{Velocity per}\\ \text{minute.}\end{array}\right.$$

Gallons per hour delivered—

$$\frac{\left.\begin{array}{c}\text{Velocity per}\\ \text{minute}\end{array}\right\} \times \left\{\begin{array}{c}\text{Square of diam.}\\ \text{of pump barrel}\\ \text{in inches}\end{array}\right\} \times 60}{353} = \left\{\begin{array}{c}\text{Gals. per hour}\\ \text{delivered.}\end{array}\right.$$

Or,

$$\frac{\text{Velocity} \times \left\{\begin{array}{c}\text{Areas of pump}\\ \text{in sq. ins.}\end{array}\right\} \times 60 \times 6{\cdot}25}{1728} = \left\{\begin{array}{c}\text{Gals. per hour}\\ \text{delivered.}\end{array}\right.$$

Note that 353 = The number of cyld. ins. per gal.
6·25 = Number of gals. in a cub. ft.
1728 = Number of cub. ins. in a cub. ft.

In all calculations as to the quantity a Pump will deliver, certainly 10 per cent. should be deducted to allow for "Slip." ("Slip," in all Pumping operations means a tendency of the water (or other liquid) to fall back against the "Suction" draught of the pump.)

In reference to the Utilization of Animal power to working a Pumping Gear, the most convenient method of transmitting same is by means of a Horse Gear, such as ordinarily applied to the working of Agricultural machinery, etc., the Power being conveyed through shafting to the Gearing of the Pumps.

As already pointed out, the generally accepted power of a Horse is 22,000 Units of work per Minute; so that, having ascertained by foregoing rules the "Units of work" to be done, and adding thereto a reasonable percentage for Friction of Gear (which with Horse Gear would be probably quite 20 per cent.), and dividing by 22,000, the result will give the Number of Horses it would require to do the Work. Should it be found that more than *two* Horses would be needed to do the work, it will be found more practicable under ordinary circumstances to employ other Motive power.

The following Table offers a fairly accurate comparison as to the capabilities of Man power, Ox power, and Horse power:—

Diam. of Pump (Double-acting Lift and Force).	Quantity Raised to be per Hour.	One Man Turning a Crank would Raise the Liquid.	One Ox Working a Gear.	One Horse Working a Gear.
2 ins. diam.	225	80 feet	350 feet	560 feet
2½ "	360	50 "	200 "	350 "
3 "	520	35 "	140 "	245 "
3½ "	700	25 "	100 "	175 "
4 "	900	20 "	80 "	140 "

Under conditions in which Fuel can be obtained at reasonable cost for producing Steam, "*Direct-acting Steam pumps*" are probably the most convenient as regards Simplicity and Handiness, in cases where the duty is too high for economical usage of Animal power; and it is now proposed to consider the question of selection of suitable class and size of Steam Pumps for certain conditions of Work.

Later on, attention will be given to the desirability of using "*Water Motors*," in such cases as admit the possibility even for the purpose of Pumping water. Where such opportunities exist, it need hardly be pointed out that the preference should be in their favour over Steam pumps.

CHAPTER VI

DIRECT-ACTING STEAM PUMPS

STEAM Pumps of this class are ordinarily made Horizontal, although Vertical Steam pumps are used for special purposes, but, in any case, the general arrangement of the machine is that of placing the Pump in the line of the steam Cylinder and connecting them in such manner that the Piston-rod is prolonged to form the Pump-rod without the intervention of any Crank shaft. The whole thus makes a very compact and economical arrangement so far as the machine itself is concerned (see fig. 21).

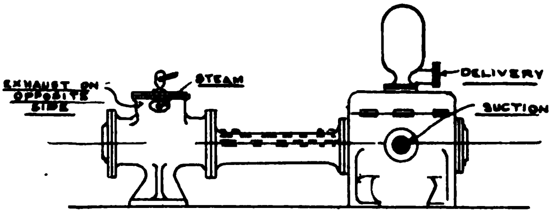


FIG. 21.

It cannot, however, be claimed that Direct-acting Steam pumps are economical as steam-driven machines, since the absence of any Crank shaft and Fly-wheel prevents the use of an efficient Valve motion to allow of working the steam expansively. Consequently, the cylinder, at every stroke, uses a full charge of steam for the whole, or nearly the whole, stroke, instead of fully utilising its expansive power. To set against this there is the advantage of fewness of working parts, and directness of action, which minimise friction to a very great extent.

To introduce greater economy of steam, "Compounding" is often resorted to, usually by attaching the "Low-pressure" cylinder at rear of the "High-pressure" cylinder on the same line of piston- and pump-rod. Thus the steam from the High-pressure cylinder exhausts into the Low-pressure cylinder, when it aids the work by Expansion of the Steam, but, of course, with added friction, due to increase of working parts. In the case of large Steam pumps, such as are frequently used for Water-works installations, a "Condenser" is often used in connection therewith.

Another arrangement of Direct-acting Steam Pumps, which presents many advantages, is that known as the "Duplex" type (fig. 22). In the ordinary arrangement of this class of pump, two steam pumps are placed side by side and connected together in such manner that the two pumps draw from the same Suction, and deliver into the same Main, and the two cylinders receive steam from the same Steam pipe. The piston-rods are so coupled together that one Steam pump is making an "out-stroke" whilst the other is making an "in-stroke," and the steam valve arrangements are so constructed that a certain amount of cut-off can be introduced and the steam used to some small extent expansively.

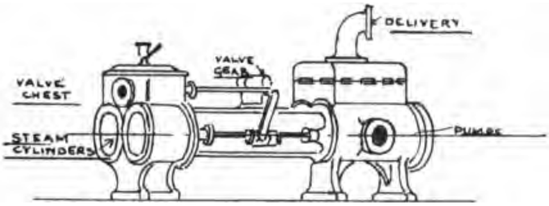


FIG. 22.

In this class of Steam pumps, also, "Compounding" is frequently resorted to.

It is not the present purpose to advocate the use of any particular type or make of steam pump, since the selection must largely depend upon special conditions, but it is now proposed to give such directions as may assist Engineers and intending users of steam pumps in deciding upon the power of pump suited to certain requirements, and to aid them in installing pumping plant to the best advantage.

Presuming that such Items as were enumerated in previous pages have been collated, the following Rules will enable the Student of the subject to make use of such Data:—

Speed of Steam Pumps.—Direct-acting Steam pumps, without Fly-wheel, possess this advantage, when working against a variable water pressure, that they will adapt themselves to this variety by running fast or slow, according to the Work, but care should be taken in so proportioning the respective areas of Pumps and Steam cylinders that under no conditions of the work should they be able to run at such speed as to cause heavy "Shocks" to the Valves or the Pipes. Thus, after the duty to be done has been ascertained, the question of *speed* becomes an important factor.

If the height of delivery is moderate and constant, the piston speed (*i.e.* the number of feet the piston or pump bucket travels over in a given time) may be taken at about 100 ft. per minute, or, for very low lifts, at even 150 ft. per minute. When, however, the delivery head exceeds 400 or 500 ft., a much slower speed is desirable, say 80 ft. per minute. Most makers of Steam pumps state the Speeds at which their Pumps should be run when proportioned for certain work, but, as they invariably state the *maximum* speed, some discretion on the part of the User is needed.

A casual examination of any Steam pump-maker's price list shows the necessity of discrimination.

As will be presently explained, the diameter of the Pump or Pumps is proportioned according to the Quantity of liquid to be delivered, the diameter of the Steam cylinder according to the *Head* such quantity has to be raised against. It follows that the larger the diameter of the Steam cylinder as compared with that of the Pump, the greater the "Lift" it is suited for, and the greater the "Lift" the heavier the force bearing on the Pump valves. Yet we find that a maker will sometimes give in a price list the same speed for a Steam pump with, say, 6-in. diameter cylinder and 5-in. diameter pump, as for 12-in. diameter cylinder and 5-in. diameter pump.

Pump valves, opening and closing, say, 100 times per minute with such "head" as the smaller steam pump would work against, must obviously work with greater absence of shock than when working at the same speed against the much greater "head" for which the larger steam pump is proportioned. To reduce the shock of the valves to an equality in the two Steam pumps, the speed of the larger one should be much less than that of the smaller one, thus allowing the valves to close more slowly This is an important point, since the Pump valves are the soul of the Pump, and are usually the most difficult parts to replace if broken or unduly worn.

When selecting a Steam pump from a maker's list, it is well to bear this in mind, and so discount the "quantities delivered" (in proportion to the ratios of difference betwixt the cylinder and pump areas) consequent upon Speed reduction.

In order to make the Rules here given more explicit, Examples are given bearing upon the particular Items.

ORDINARY DIRECT-ACTING STEAM PUMPS

Given the Quantity to be pumped and the Piston speed in feet per minute.

I. To find area of Pump bucket or Pump ram—

$$\frac{\text{Gals. per min.} \times 277 \text{ cub. ins.}}{\text{Speed of piston} \times 12 \text{ ins.}} = \text{Area of pump piston in sq. ins.}$$

(Note 277 = the number of cub. ins. in 1 gal.)

Example.—100 gals. per min. to be pumped. Speed of piston 60 ft. per min.

$$\frac{100 \times 277}{60 \times 12} = 38{\cdot}4 \text{ sq. ins.}$$

Upon reference to the Table of Areas (p. 109) it will be found that 38·4 is the area of 7 *ins. diam.*

Given the Area of Pump piston (as above) and the Head of Water.

II. To find total pressure upon Pump piston—

$$\left.\begin{matrix}\text{Area of Pump}\\ \text{piston in sq. in.}\end{matrix}\right\} \times \text{Head in ft.} \times {\cdot}434 = \left\{\begin{matrix}\text{Total pressure in lbs.}\\ \text{on Pump bucket.}\end{matrix}\right.$$

Example.—Head of Water, inclusive of Vertical Suction and Head due to Friction, say 500 ft.

$$\text{Area, } 38{\cdot}48 \times 500 \text{ ft.} \times {\cdot}434 = 8350 \text{ lbs.}$$

Thus giving the total Load on Pump.

Given the Steam pressure per square inch available, and the Load upon the Pump.

III. What should be the Area of the Steam piston?

1. To find what area of Piston would balance the Load on the Pump—

$$\frac{\text{Total load in lbs. per sq. in. on pump}}{\text{Steam pressure per sq. in.}} = \left\{ \begin{array}{l} \text{Area of Piston to} \\ \text{balance Pump load.} \end{array} \right.$$

2. To overcome the inertia of the water column and set it in motion at the required speed, the power of the Steam cylinder should be 40 to 50 per cent. in excess of the Resistance—

$$\text{Thus} \quad \left. \begin{array}{c} \text{Area of piston to} \\ \text{balance the column} \end{array} \right\} + 50 \text{ per cent.} = \left\{ \begin{array}{c} \text{Required area of} \\ \text{steam piston.} \end{array} \right.$$

Example.—Pressure of steam, say 80 lbs. per sq. in.; Load on Pump, as per Rule II., 8350 lbs.

$$\text{Then} \quad \frac{8350}{80} = 104{\cdot}37, \text{ area in square inch to balance;}$$

$$104{\cdot}37 \times 1{\cdot}5 = 156{\cdot}55 \text{ sq. in. Steam piston area required.}$$

$$\text{Diam. corresponding to this area} = 14\tfrac{1}{8} \text{ ins.}$$

The nearest Commercial size would be a 14-*in.* diam. Steam Cylinder. So that the size of Steam pump, suited for the duty named in above example, would be 14-*in. Cylinder* and 7-*in. Pump*.

Presuming that a certain size of Steam pump is available, it is required to know what "Duty" it is suited for.

Example

A Steam pump (of Direct-acting Type) has a 9-in. Cylinder and a 6-in. Pump, with 10-in. Stroke.

Required to ascertain of such Pump: the number of gallons of water it should deliver through a 3-in. diameter pipe, and to what *height* it should deliver with 50 lbs. per sq. in. of Steam pressure. (A Steam pump of such size may be run at, say, 100 ft. piston-speed per min.)

Rules

1. Multiply the area of Pump bucket by the Speed in ins. per min., and again by the number of Gals. in a Cubic foot, and the sum divided by 1728 cub. in. will give the number of Gals. per min. the Pump should deliver.

Area of 6 ins. = 28·27 sq. in.

$$\frac{28{\cdot}27 \times 100 \times 12 \times 6{\cdot}25}{1728} = 122{\cdot}7 \text{ Gals. per min.}$$

Then $122{\cdot}7 \times 60 = 7362$ Gals. per hour Pump should deliver.

(From this should be deducted, say, 5 per cent. to 10 per cent. for "Slip.")

2. To what height in feet should it force the above quantity of Water with, say, 50 lbs. pressure per sq. in. of Steam?

Multiply the area of the Steam piston by the Steam pressure, and divide product by area of Pump bucket. Result gives number of lbs. per sq. in. acting upon the Piston.

Area of 9 in. = 63·61 sq. in.

$63{\cdot}61 \times 50 = 3180{\cdot}5$ lbs. pressure on Steam piston.

Then $\frac{3180{\cdot}5}{28{\cdot}27} = 112{\cdot}48$ lbs. Pressure per sq. in. on Pump bucket.

3. Of this force conveyed to the Pump piston, one-third will be required to *move* any column of water bearing upon it; the remaining *two-thirds* will give the "Pressure head," in lbs. per sq. in., that can be set in motion.

Thus $112{\cdot}48 \times \frac{2}{3} = 75$ lbs. per sq. in.

75 lbs. $\times {\cdot}434 = 175$ ft. Head,

which is the height to which the Steam pump in question would deliver with 50 lbs. steam pressure.

To estimate the Friction due to the delivery of 122·7 Gals. per min. through 175 ft. of 3-in. pipe, proceed according to Rule already given *re* "Friction."

$122{\cdot}7^2 \times 58{\cdot}3$ yds. $= 873207$;

$$\frac{873207}{(3^d)^5} = 14{\cdot}8 \text{ Friction head in ft.}$$

Note.—Tables are published that would obviate this calculation as to Friction head (see Table III., p. 111).

It was found that without taking "Friction head" into account the Steam pump would deliver to a height of 175 ft., but, as there would be friction equivalent to a head of 14·8, that should be deducted.

175 ft. - 14·8 ft. = 160·2 ft.

The net height to which the Steam pump would deliver with 50 lbs. steam.

Thus we find that a Direct-acting Steam pump, having 9-in. diameter Cylinder × 6-in. diameter Pump, 10-in. stroke, running at 100 ft. per min. piston speed, with 50 lbs. steam pressure, will deliver about 7000 gals. of water per hour, to a height of 160 ft. through 3-in. diameter pipes.

DUPLEX DIRECT-ACTING STEAM PUMPS

As already explained, a "Duplex" Steam pump really consists of two ordinary Direct-acting Steam pumps coupled together, but with such gearing as allows of some greater use of the expansive force of the steam, and also regulates the pump strokes, so that one pump is taking the in-stroke whilst the other makes its out-stroke (see fig. 22). It will be obvious that, as two pumps are engaged in the work, both of equal capacity, each is doing one-half of the whole work. Thus the requirements as to size of cylinders to perform the same duty, as in the example already given, would work out as under:—

Required to know what size of "Duplex" Steam pump should be adopted to deliver 100 gals. of water per min. against a head of 500 ft., at a piston speed of 60 ft. per min. with a steam pressure of 80 lbs. *Each* pump would have to deliver 50 gals. per min. Proceed according to Rules given on preceding pages.

Example.—$\frac{50 \text{ gals.} \times 277 \text{ cub. ins.}}{60 \times 12 \text{ ins.}} = 19{\cdot}23$ sq. in. Area of Pump.

Or approximately 5 in. diam.

Area of Pump, 19·23 × 500 ft. × 434 lbs. = 4173 lbs.
being the total load on Pump.

$\frac{4173}{80} = 52{\cdot}16$ = Area of cylinder to balance load on the Pump.

52·16 × 1·5 = 79·24 = Required area of Cylinder.

The nearest commercial size = 10 ins. diam., so that the Duplex Pump would be 10-in. diameter Steam Cylinders, and 5-in. diameter pumps.

BOILER POWER

The next important question to consider is that of the Boiler power required to work the Steam pumps. The selection of the *class of Boiler* must, of course, be guided largely by circumstances, such as kind and quality of fuel available, or question of "setting up." It may, however, not be out of place to suggest that for simplicity, portability, and general handiness, for small pumping plants, the Vertical Boiler on Bedplate or the Semi-portable Locomotive type of Boiler are preferable.

Referring to the examples already given of a simple Direct-acting Steam pump, 14-in. Steam cylinder and 7-in. pump, having presumably 12-in. stroke and running at 60 ft. piston speed per min., steam pressure 80 lbs. per sq. in., and height of delivery = 500 ft.

1. As to "Units of work" to be done under the conditions named (see previous pages).

$$\frac{100 \text{ Gals. per min.} \times 10 \text{ lbs.} \times 500 \text{ ft.}}{33{,}000} = 15 \text{ H.P. approximately.}$$

2. Rule for ascertaining Boiler power required—

$$\frac{\left.\begin{matrix}\text{No. of Gals.}\\ \text{per min.}\end{matrix}\right\} \times \left\{\begin{matrix}\text{Piston speed per}\\ \text{min. in ins.}\end{matrix}\right\} \times 60}{1728 \text{ cub. ins.}} = \left\{\begin{matrix}\text{Cub. ft. of steam}\\ \text{used per min.}\end{matrix}\right.$$

and

$$\frac{\begin{matrix}\text{Cub. ft. of steam}\\ \text{per min.}\end{matrix}}{\begin{matrix}\text{Volume of steam at}\\ \text{80 lbs. pressure}\end{matrix}} = \left\{\begin{matrix}\text{Number of cub. ft. of water evaporated}\\ \text{per hour.}\end{matrix}\right.$$

And as 1 H.P. requires the evaporation of 1 cub. ft. of water per hour, the above gives the number of H.P. required in Boiler Power.

Example.—Area of 14 ins. = 154 sq. ins.

$$\frac{\text{Area } 154 \times 60 \text{ ft.} \times 12 \text{ ins.} \times 60 \text{ mins.}}{1728} = 3850 \text{ cub. ft.}$$

$$\frac{3850}{295} = \left\{\begin{matrix}\text{13 cub. ft. of water evaporated (295 being the volume}\\ \text{of steam at 80 lbs. pressure see Table VIII.).}\end{matrix}\right.$$

So that 13 H.P. Boiler would be required.

Since a certain amount of loss of steam takes place by Condensation, etc., during its conveyance from the Boiler to the Steam Cylinder, it will be well in all cases to add 20 per cent. to the result obtained by the foregoing Rule when deciding upon the power of Boiler required. This would give 15·60 H.P. As 15 H.P. is the nearest commercial size, one would use a 15 *H.P. Boiler.*

By the use of "Condensers" greater economy can be introduced and Boiler power saved, though, excepting in the case of Compound Steam pumps, they are rarely employed.

Space does not permit of considering the question of Compounding, but as a guide to the proportioning of the High-pressure and the Low-pressure cylinders, it may be said that the latter should be about twice the diameter of the former, or more correctly thus:—

The total Effective pressure of steam upon the high-pressure cylinder and the low-pressure cylinder being added together should be about *double* the total Water pressure on the pump, or, at any rate, should not be less than 1·6 of the Water pressure. Or, divide the total pressure of the Pump bucket by the average pressure of steam to find the area of the Low-pressure cylinder. This divided by the number of the expansions of the steam will give the area of the High-pressure cylinder.

Before leaving the subject of "Steam Pumps," it is desirable to point out that under this head is included not only such machines as are in requisition for moderate pumping installations, but such as are needed for Mine and Colliery purposes, and that, although it is not possible within the limits of such a Treatise as this to enumerate the various arrangements of Pumps applicable to heavier work, still the principles involved in their arrangements are identical with those described.

Some little explanation of the terms "Nominal Horse Power" and "Indicated Horse Power" may here be given.

The former term is one conveying but little meaning, as its value is variable; every maker of a Steam-engine or an Engine working by any other agency may, and does, fix its nominal H.P. value on his own terms, assuming that certain dimensions constitute a Nominal H.P. In Condensing engines a very ordinary rule is to allow about 9 to 10 sq. ins. of piston area per Nominal H.P.

"Indicated Horse Power," on the other hand, is a definite term, based upon the *actual work* the Engine performs in *Units of Work*, and it is usually about 2½ or 3 times the *Nominal power*. Its basis is ordinarily obtained by the use of an Instrument termed an "Indicator," by means of which it is possible to ascertain with great exactitude what forces are at work in a Vapour or a Water Cylinder.

CHAPTER VII

CENTRIFUGAL PUMPS

THUS far attention has been given almost exclusively to Reciprocating Pumps, but there is also a class of "Rotative" Pump demanding notice, of which the Centrifugal Pump may be accepted as the best known.

The ordinary construction of a "Centrifugal Pump" is that of a set of revolving arms, or Vanes, within a closed casing, having a Central inlet for the water, and a Tangential outlet for same.

Of a necessity such pump must be operated through the medium of extraneous power, and its action may be summarised as follows:—

The rotative action of a set of Vanes (usually about six in number), running at considerable speed, imparts a Centrifugal motion to a body of water in the pump casing, propelling it forward, and at the same time inducing a vacuum in the suction, or supply pipe, thus raising a further supply to the pump, and producing a continuous flow.

A considerable quantity of water may be thus raised by suction from a moderate depth, and delivered to a moderate height in a very full flow, and (according to the speed) the quantity delivered may be fairly gauged.

The makers of Centrifugals are usually inclined to claim a much larger range of utility for them than they are really entitled to. Where the question is that of delivering a considerable quantity of liquid to moderate height, say up to 40 ft. above the machine, in a short period of time and with moderate expenditure of power these machines find their best vocation; but where the delivery exceeds that height, greater economy will probably result from usage of a reciprocating pump of good construction.

For such purposes as pumping out large bodies of liquids from moderate depths, and delivering to a limited height, they are inestimable, as in Wrecking work, pumping out Foundation works, emptying "Floating" and "Graving Docks," etc. In Irrigation work they have also proved exceedingly valuable.

Amongst the advantages possessed by the "Centrifugal" pump the following bear weight:—

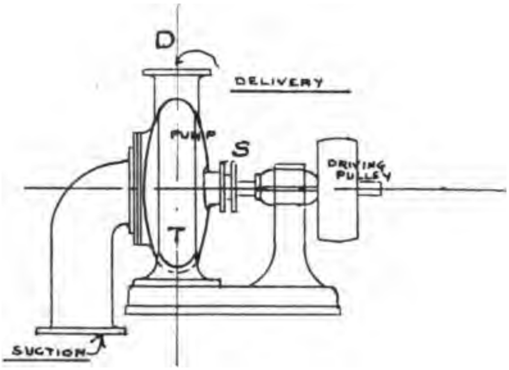


FIG. 23.

Under suitable conditions a large quantity of liquid may be delivered compared with the size of the machine, and the cost of same.

It is inexpensive to erect, being simple in construction and compact in form.

If the liquid passing through it is foul and dirty, it does not injuriously affect the action of the machine.

The "Vanes" or "Blades," being mechanically constructed, the machine should give an "efficiency" of about 60 per cent. to 65 per cent. Centrifugal pumps admit of a variety of methods of attachment to their Motors, it being a very common practice to attach an engine directly on to the shaft of the pump, thus saving any intervention of Gearing, or belting and pulleys.

The greatest depth from which an ordinary Centrifugal pump will "draw" water by suction is 22 to 23 ft., but it is best not to exceed about 16 ft.

Arrangement should be made for the outlet of Air at the top of the pump casing, and for charging the same with water. The Suction pipe should have a Foot-valve attached. If liable to the action of frost, a cock should be provided *below* the pump for emptying the pump and pipes if needed.

Figs. 23 and 24 are intended to give an idea as to the ordinary form of "Centrifugal pump." The Wheel itself is carried upon an axle prolonged through stuffing boxes S, attached to the pump casing T. The Vanes, V V, are curved in the direction of the flow of liquid, which, entering at the *centre* of the wheel, is thrown forward into the Delivery pipe D, which pipe may be arranged at any desired angle to suit any special purpose. The wheel is operated through motive power applied to its axle by driving belt and pulleys, or by direct attachment to the Motor.

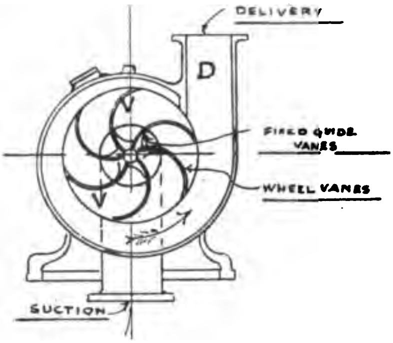


FIG. 24

There are various other Rotary Pumps, which space will not admit description of, both for Hand power and Mechanical driving, but the "Centrifugal" type would seem to be the simplest and most efficient for fairly heavy work.

A most especial feature in favour of pumps of this class is their compactness, and the facility with which they can be coupled on to a motor of any kind, or arranged in a portable form.

Below is appended a Table giving the quantities of water Centrifugal pumps of good proportion are calculated to discharge:—

Diameter of Discharge Pipe in inches.	Number of Gallons Discharged per minute.
6 inches	500 to 750
8 „	1000 „ 1500
10 „	1500 „ 2000
12 „	2000 „ 3000
16 „	4000 „ 5000
18 „	6000 „ 8000

In "lifts" varying from 15 ft. to 35 ft. the larger quantities are of course the delivery at the lowest "lifts."

CHAPTER VIII

HYDRAULIC POWER MACHINERY

UNDER this head may be included "Hydraulic Presses," "Hydraulic Jacks," "Hydraulic Lifts," and other machines deriving power from the pressure of water.

It has already been explained at some length, when referring to the Laws governing the pressure of liquids, that they possess the capability of transferring pressure equally in all directions. So that, given a quantity of liquid entirely filling a closed vessel, or several vessels communicating with one another, if a pressure be brought to bear upon any portion of the surface of the liquid, at any part of the containing vessel or vessels, the like amount of pressure is communicated to every part of the surface of said vessel.

For example, if a pressure of 100 lbs. be applied to one particular square inch of the liquid surface (the vessels being water-tight), a force of 100 lbs. will be communicated to every other square inch of the surface of all the containing vessels. If then, there should be two cylinders of unequal size in connection with one another, and a pressure is produced upon the smaller cylinder by a piston, it will result that such pressure will be conveyed to the larger cylinder and exert a force therein greater than that on the surface of the smaller cylinder in proportion to its *greater* area.

If the larger cylinder be, say, 10 in. diameter, and the smaller 1 in. diameter (each being fitted with a piston), the areas will be as 1 to 100. Then a pressure of 100 lbs. being exerted on the piston of the smaller cylinder, a pressure of

10,000 lbs. would be exerted upon the piston of the larger cylinder.

It follows that, if the piston of the smaller cylinder be forced inwards with a pressure of 100 lbs., it would raise a weight of 10,000 lbs. resting upon the piston of the larger cylinder. If the smaller piston travels, say, 1 in., it will raise the larger piston with its superincumbent weight $\frac{1}{100}$ part of an inch only. So that the *gain in power* is in direct proportion to the *loss in speed.*

In the application of Hydraulic power, the method indicated above is that usually employed, *i.e.* a pump of small diameter is used to force water into a cylinder having a ram or piston of larger diameter. One of the first considerations, therefore, when adopting such power is, how far it is proposed to sacrifice "speed" to "power," or vice versa, and upon these lines the proportions of the cylinders may be settled in the case of a Hydraulic Press.

It is hardly necessary to point out that hydraulic pressure may be brought to bear upon a Press, or for Raising a weight, by other means than using a pump.

For instance, a small pipe may be erected vertically, where a water supply can be obtained at an elevation, its lower end connecting with a Hydraulic Cylinder, in precisely the manner indicated in figs. 3 and 5. If such a pipe be kept supplied with water, it will exert a force upon the piston of the press proportionate to the height (or Head) of water in the small pipe. The diameter of such pipe is immaterial, always provided that it is sufficiently large to obviate undue friction and allow a free flow of water.

Presuming such a pipe to be 100 ft. in height, connected at lower end to a Hydraulic press cylinder of 9 in. diameter.

The pressure due to a head of 100 ft. is

$$100 \times \cdot 434 = 43 \cdot 4 \text{ lbs. per sq. in.}$$

The area of 9 in. = 63·61.

So that $63 \cdot 61 \times 43 \cdot 4 = 2760$ lbs. pressure which would be exerted upon the 9-in. piston. In order the more clearly to explain the mechanical arrangement of the "Hydraulic Press" in its simplest form, see fig. 25.

A is a small Power pump of strong make, with admission valve C, communicating by pipe D with the cylinder E of a Hydraulic press, of which F is the Ram, G the Gland with Water-tight packing, H the Head, to which may be attached any mechanical arrangement for the conveyance of the power according to requirements.

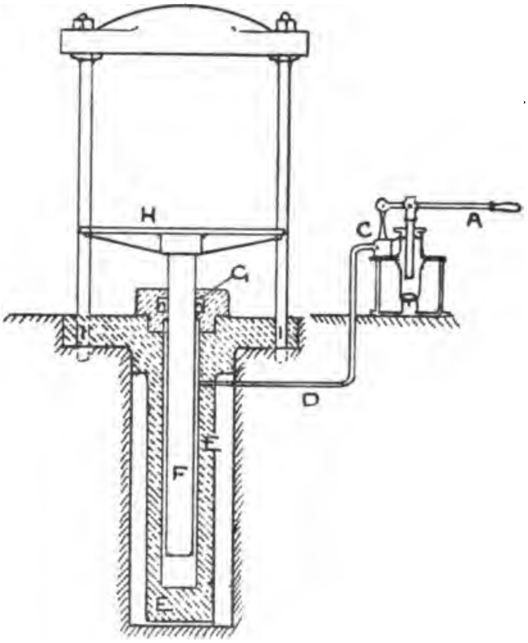


FIG. 25.

It is only necessary to point out that the machine may be horizontal or at an angle, as desired, and that the Power pump may have more than one barrel; and may be operated by steam, hand power, or any other medium.

When used for working "Lifts," pulley sheaves are ordinarily fixed in the "head" of the Ram F, which may communicate by chain, or wire rope, with the "Lift" or other machine it may be required to work. When used for Pressing purposes, the work is generally brought to bear by means of a Rising Table attached to the Head, and pressing upwards against another Fixed Table. There are, however, many varieties of Presses made to suit the needs of users, but the principles governing their construction are identical, and there is no definite limit to the power they may be made to exert, saving the strength of the materials used.

Hydraulic pressure is very largely used in Docks, large Warehouses, and Packing Establishments, and of late years it has been largely introduced on Men-of-War and in Fortifications for manipulating heavy guns.

In some large cities it is now conveyed over large areas in strong underground pipes, and the power rented to Factories, etc., for working Lifts, Hoists, or light Hydraulic Machinery, the users paying by "meter" measurement for the quantity used.

An exceeding useful adjunct to a Hydraulic plant is the "Accumulator," the function of which is to store up the Pressure being generated by the Power pumps whilst the Press or Presses are not in actual operation, and also to act as a Governor in steadying and regulating the pressure as received from pumps.

Its ordinary construction is similar to that of a Press itself with the Ram heavily weighted, working in a cylinder the capacity of which should be equal to the full quantity required for one charge of all the presses supplied through it. See fig. 26, in which A is the Accumulator Cylinder; B the Ram working in same through a Gland at G; C is a heavy ring of metal made to slide loosely on the Cylinder A, and suspended from the Ram head by rods D D. Water is forced into the cylinder through the back pressure valve E until the Ram is raised to the top of its stroke, and is kept under pressure by the weight of C, until released as required through the stop-valve F. It should be fitted with a safety-valve to allow for the relief of any surplus pressure.

A variation of the ordinary "Accumulator" is the "Differential Accumulator" arranged somewhat as per sketch, fig. 27. It has two Pistons of unequal diameters, attached to opposite ends of the same piston-rod, working in cylinders placed in line. The pressure of water in the large Cylinder is communicated by the larger Piston to the smaller one, and thus the pressure per square inch is increased, in the ratio of the difference of their areas.

Presuming the larger Piston to be 12 ins. diameter, and the smaller one 4 ins., their areas will be in the proportion of 144 to 16. So that, if there be a pressure of 500 lbs. per sq. in. on the larger Piston, it would produce a concentrated pressure of 4498 lbs. upon the smaller one as under:—

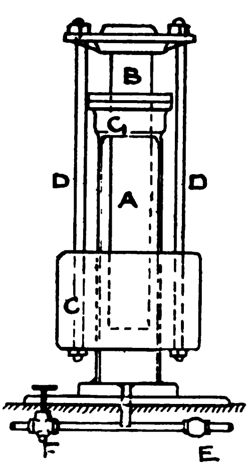


FIG. 26.

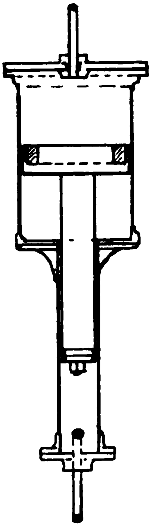


FIG. 27.

Area of 12 ins. = 113. Area of 4 ins. = 12·56.

Then $\frac{\text{Area, } 113 \times 500 \text{ lbs.}}{12\cdot56} = 4468$ lbs. total pressure, say 4500 lbs.

Or $\frac{500 \times 144}{16} = 4500$ lbs. total pressure.

The purposes to which Hydraulic power commends itself are so numerous that it would be useless to attempt to detail them, but the explanations given above as to the Principles of its application will readily suggest to the reader's mind examples of its usefulness.

The Baling of Loose materials, Pressing oils from Seeds, Roots, etc., Punching, Riveting, and Testing the strength of Metal work, Raising and Forging heavy Weights, and Working Cranes and Hoists, are a few of the purposes to which it is most largely applied.

Hydraulic Lifting-Jacks are really small Hydraulic presses in which, for the sake of convenience and compactness, the pump cistern, valves, etc., are usually all contained in the body of the Machine. They are made in sizes suitable for lifting from 4 to 5 tons, up to 50 tons or more.

Hoists and Lifts.—These are two ordinary applications of Hydraulic power in this connection.

In ordinary "Lifts" the weight is lifted by direct action, the cylinder being sunk in the ground vertically below the ground level, the ram being necessarily somewhat longer than the full height of the "Lift."

Hoists are frequently worked by much shorter Hydraulic cylinders placed in any suitable position, the Ram carrying "Sheaves," or Grooved pulleys working chains, or wire ropes, connected to other pulleys in such manner as to *multiply* the length of the original stroke.

It will not be amiss here to again call attention to the fact that such multiplication must be made at the expense of *time* in accomplishing the work, and that this should always be borne in mind when arranging such work.

Hydraulic power applied by means such as already mentioned has so many advantages that it is surprising it has not been more extensively adopted, especially as there are innumerable cases where the power may be said to be *ready made* and at hand.

It is so readily conveyed and controlled, and by Mechanical arrangements can be employed for so many useful purposes, that it argues a want of appreciation of its qualities in many instances where it could be advantageously applied.

As a means of testing the strength of Boilers, or other Closed vessels, Hydraulic pump power is invaluable. The

Boiler or other vessel being filled with liquid, immense pressure can be brought to bear by means of very small pumps, and any leakage or weakness can be readily detected. Such testing, moreover, can be conducted with much greater security than testing by Steam, as the pressure can be relieved as readily as it can be applied.

The Author has on several occasions, when designing Hydraulic Machinery, made good use of a simple arrangement of Telescopic Rams, which figs. 28 and 29 will serve to explain.

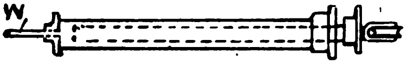


FIG. 28.

A cylinder A of, say, 6 in. diameter inside, and of any desired length, is closed at one end with the exception of a small opening to allow of the supply pipe being attached, and the other end is fitted with a Stuffing-box and Gland. Into this Gland is fitted another cylinder B, say, 4 in. in diameter, closed with the exception of a small opening (say, ¾ in. diameter) at its bottom end, and the top end fitted with another Gland. In this Gland is fitted a still smaller Cylinder C, say, 2 in. in diameter, the lower end closed entirely, the upper carrying a pulley or other appliance for conveying the Power.

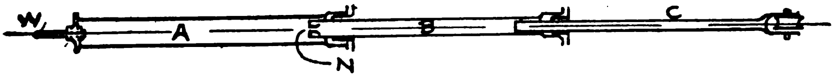


FIG. 29.

Presuming a water pressure of 100 lbs. per sq. in. is applied through the pipe W, when all the cylinders are closed, as in fig. 28. Then, as the areas of the movable cylinders are respectively

B 4-in. diam. = Area 12·56. C 2-in. diam. = Area 3·141.

The total pressure upon B 12·56 × 100 = 1256 lbs.

„ „ „ C 3·141 × 100 = 314 lbs.

The bottom of the hollow Cylinder B has an opening at N connecting to cylinder A, but C has no opening into B. It follows that B will therefore be forced out to the end of its stroke, carrying C with it. As B can advance no further, then C will be forced outward to the end of its stroke, when the whole would be extended as shown in fig. 29.

There are many purposes to which an arrangement such as this is applicable, notably in raising any heavy body where a greater force is required to overcome its inertia and get it started, than is required to *keep* it in motion; or in a case where more power is required on some occasions than at others. If the smaller Ram can do the work, it *will*; if it cannot, the next larger one will take it up, and so on.

The following numbers will be found useful in ascertaining the quantity and weight of water required for working Hydraulic Machinery:—

D being the diameter of Cylinder in inches.
S being the length of the Stroke in inches.

$$\text{Then }\left.\begin{array}{ll} D^2 \times S \times \cdot 7854 & = \text{Cubic inches of water} \\ D^2 \times S \times \cdot 002833 & = \text{Gallons of water} \\ D^2 \times S \times \cdot 02833 & = \text{Lbs. weight of water} \end{array}\right\} \text{per stroke.}$$

To those inexperienced in Hydraulic Machinery it may seem difficult to regulate and control the great forces that may be developed, and yet no power admits of more easy and delicate manipulation. Rams, rods, etc., are easily kept water-tight by simple leather packings in the form of Cupped leathers or rings. These Cup leathers are shaped by Hydraulic pressure in iron moulds, and are made from specially prepared leather, pressed whilst the leather is moist, and kept in the moulds until dry, so that they retain the requisite shape.

The Pressure water acts upon the inside of the U-shaped leather, and forces the one side against the surface of the Ram and the other side against the Walls of the recess, in which the leather is placed. The greater the pressure the greater the force with which it is pressed outwards.

Controlling valves operated by hand levers, the plungers of which need not exceed 1 in. to 1½ in. diameter, and having only 2 or 3 ins. stroke, may be so constructed as to control the action of Hydraulic Machines, exerting many tons pressure, and may be operated by a child. Such controlling valves can be simply and efficiently packed by rings of leather, not more than ⅛- or 3/16-in. square in section. Such rings will prevent any pressure water from passing them, and by moving the valve up or down any ports may be closed or opened, or put in communication with one another, according to the arrangements of the rings and the recesses. The Writer has arranged three such valves in one casting, not more than 1 ft. square, controlling six sets of Hydraulic Telescopic Rams, as fig. 28, and working heavy Travelling Cranes, all Travelling, Traversing, Lifting, and Lowering being done by one operator.

CHAPTER IX

HYDRAULIC RAMS

THERE frequently exist conditions where it would be of advantage to expend *part* of a supply of Water for the purpose of delivering a smaller portion thereof to some higher elevation, and for such purpose the "Hydraulic Ram" is a most suitable medium.

As with other Hydraulic Motors, the power is obtained by utilisation of a fall of Water, but inasmuch as this class of machine can be worked with either a constant or an intermittent flow from a Stream or Spring, with a Head as low as 3 or 4 ft., forcing water to many times the height of the head, and as it is entirely self-acting, and will continue working without attention for an indefinite period, it is an exceedingly useful machine when fixed under suitable conditions.

The sketch given in fig. 30 shows the simplest form of this Machine, and its description will largely serve to make plain the principle upon which Hydraulic Rams work:—

N being a Tank, Reservoir, or Stream.
D an inclined pipe from same to some position where a free outlet can be obtained.
C a valve operating outwards with free opening at F.
E a delivery pipe to a trough at T.
a b the highest level to which water can rise in the "Race."

The action of the Apparatus is as follows:—Whilst water has a free escape through the valve opening at F, the water in the pipe D is acquiring Velocity and Momentum, due to the head of water from N, which eventually causes the closing of the Valve C. When this takes place the momentum of the Column of water in D will still be sufficient to cause a flow up the pipe E, so that some part of the water will reach the trough T.

The Momentum of the water being thus expended in raising a part of the flow to an elevation above the valve C, it comes to rest, and the "head pressure" in the delivery pipe E then causes the valve C to close on its seat and prevent any outflow at F. Reaction then takes place, and part of the Water returns to N, until relief of pressure allows the valve at C to again open, when the cycle of operations is repeated.

A simple apparatus of this kind may be used to raise water to a small elevation, say as high above the water level at N as that level is above the Tail Race level *a – b*.

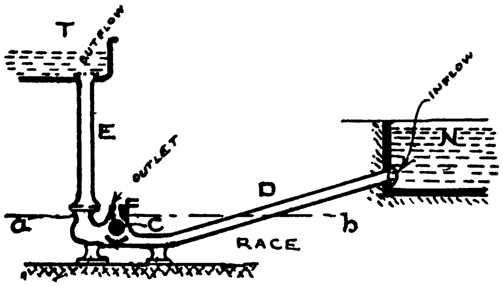


FIG. 30.

In its more advanced form the Rebounding action of the water is brought to bear upon air confined in a vessel, compressing it in such manner that its after expansion is utilised to drive a portion of the water up a delivery pipe to a height proportioned to the *original force* of the water entering the Ram.

Fig. 31 illustrates the general arrangement of such a machine.

The water under pressure due to the "head" in the inclined pipe A (usually termed the "Drive pipe") flows into the Ram R, and by its momentum closes the weighted valve C, thus cutting off escape of the water at the opening D. The sudden check of its flow, due to the closing of C, causes the opening of the valve E, and allows an inrush of water into the Air Vessel F, which compresses the air in the upper part of this vessel, forming an Elastic Cushion. The impulsive force of the water being thus expended, the weighted valve at C falls and allows water to escape at D.

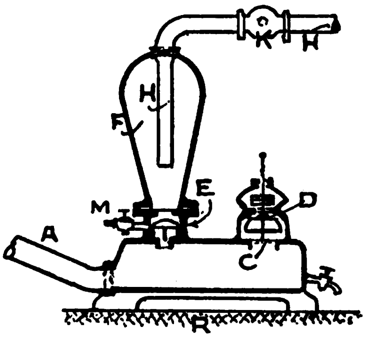


FIG. 31.

The air compressed in the Air Vessel at F now expands, closing down the valve at E, and by its expansive force driving a part of the water contained in the vessel up the delivery pipe H.

The valve at C is so weighted that it falls quickly, allowing Relief of Pressure, and it is upon the proper balancing of this Valve that the efficiency of a Water Ram very largely depends, as, if improperly weighted, heavy shocks may occur, or much "slip" of water may result.

In the delivery pipe H is fixed a Retaining valve K, the function of which is to prevent the return of water into the Air Vessel during following pulsations of the Ram. A suitable Air valve, or "Snifting Valve," M is inserted in the neck of the Air Vessel to allow of the admission of a "snift" of air at each pulsation of the machine, thus keeping the air chamber charged with air.

As will be seen, there are no moving parts in the machine other than the Valves, and their movement being quite automatic, the machine should require no attention save occasional cleaning.

The quantity of water the machine will deliver to a superior elevation amounts to only a small proportion of the *whole* quantity flowing into the apparatus, the remainder being run to waste. Any Stream having a velocity of anything over 15 ft. per second will suffice to work a Ram.

The pipe conveying the water to the Ram should be laid with an inclination downwards towards the Ram of, at least, 1 ft. in every 2 *ft. of length*, and it should be from 25 ft. to

50 ft. in length, according to the height of Delivery in the Rising main H. This pipe, if 2 in. diameter or under, may be of wrought-iron, but, if over that diameter, cast-iron Spigot and Socket pipes will be usually found the least costly.

The Height of the Supply Reservoir above the Ram should, for favourable results, be about $\frac{1}{20}$ of the height to which the water has to be delivered, and it should never be less, at any rate, than 8 to 10 ft.

A rough Rule for calculating the duty of a "Hydraulic Ram" is as follows:—

To force water to a height and through a length of, say, 150 to 200 yds. of pipe, properly proportioned, it may be estimated that $\frac{1}{6}$ of the water passed to the "Ram" can be discharged at an elevation 5 *times* as great as the "Head" of the Supply. $\frac{1}{12}$ of the supply may be forced to a Height 10 times the "Head." $\frac{1}{24}$ of the supply may be forced to a Height 20 times the "Head."

The Efficiency of the "Hydraulic Ram" decreases rapidly in proportion to the increased height of delivery.

To ascertain Percentage of Efficiency.—Divide the Height of the "Lift" by the Height of the "Fall," and below the figure corresponding to the result will be found in the percentage of efficiency:—

Lift-Fall . .	4	6	8	10	12	14	16	18	20	25
Efficiency . .	·75	·68	·57	·48	·38	·32	·23	·17	·12	·10

Thus,

To deliver water 60 ft. high with 15 ft. Fall the Efficiency = ·75.
" 144 ft. " 12 ft. " = about ·38.

Given the quantity of water in cubic feet delivered to the Ram per second.

To find diameter of supply pipe in terms of feet

$$1{\cdot}45 \times \sqrt{\text{of quantity}} = \text{diameter in feet.}$$

To find diameter of delivery or Rising main

$${\cdot}75 \times \sqrt{\text{of quantity}} = \text{diameter in feet.}$$

The proportioning of the valves in a Hydraulic Ram is the province of the Manufacturer, so that it is needless to go fully into that question. When ordering a Ram, however, it will be well to fully inform the makers as to the selected position for placing it relative to the Supply. In this connection it is well to state that the Supply pipe (or "drive pipe") should be of considerable length and laid straight, avoiding any bends as far as possible, and having an inclination (as already stated) of at least 1 ft. in every 2 ft. towards the Ram. Since the section of the machine is dependent upon the valve *suddenly arresting* the flow of the supply water, and by its "Reactionary force" compressing the air in the Air Vessel, it is important that this matter of arrangement ot the "Drive pipe" should be carefully considered.

The contents of the Air Vessel in cubic feet should equal the contents of the "Rising main" (or "Delivery" pipe).

Beside the arrangement of Hydraulic Rams as above described, other adaptations of the apparatus are constructed to deliver Clean water from one source of supply, whilst the machine is operated by Dirty water from another source.

Since the Hydraulic Ram is an *Automatic* pumping appliance, it affords a most useful medium for pumping water from a Spring or small Stream to Storage tanks at a higher elevation, and by a very simple arrangement of Supply tank intermittent or scanty supplies may be utilised.

A very efficient Storage tank for small or intermittent supply is illustrated at fig. 32.

A is a Cistern or Reservoir, into which the water from a Spring is led by the pipe or trough B. C is the pipe leading from the Cistern to the Ram ("Drive pipe") closed by a weighted, hinged valve D, operated by a chain led over a grooved pulley E. To the other end of the chain is attached a metal vessel F, the weight of which is a little less than that of the valve D. A small pipe is led through the wall of the Reservoir at H to deliver water into the vessel F, at bottom of which vessel are two or three small holes (about $\frac{1}{16}$ in. diameter). The action of the apparatus is this: Water trickles into the cistern from B until its level reaches the small pipe H, when part of it flows through and fills, or partially fills, the vessel F until its weight, acting through the chain and pulley, opens the valve D, and allows the water collected in the Cistern to flow through C to the Ram, whence part of it is forced up to the required point. The weight of water in the Vessel F holds the valve open, until the water has run from F (through the small holes referred to above), when, the water being exhausted in A, the weighted valve closes, and allows the cistern again to fill and provide a fresh supply to the Ram.

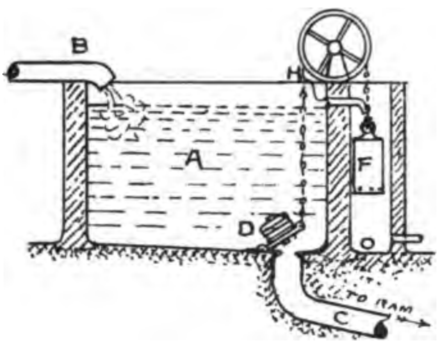


FIG. 32.

The following Rules and Memoranda in relation to flowing Water will be found serviceable:—

To ascertain the Theoretical Velocity of Water flowing through a pipe:—

Rule.—Multiply the Square Root (see Table II.) of the Head of water in feet by 8·03; the product is the Theoretical Velocity in feet per second.

Example.—Required Theoretical Velocity due to a "Head" of water of 25 ft.

$$\sqrt{25} = 5,$$

and $5 \times 8{\cdot}03 = 40{\cdot}15$ Velocity in ft. per sec.

(See also Table IX.)

Or, Multiply the Head of water in feet by 64·4, and the Square Root of the Product will equal the Theoretical Velocity in feet per second.

Example.— $25 \times 64{\cdot}4 = 1610.$

$$\sqrt{1610} = 40{\cdot}14 \text{ ft. per sec.}$$

Note.—That in practice it is sufficiently near to take 8 and 64, omitting the decimal in the two above Rules.

To ascertain the quantity of water discharged.

Rule.—The velocity in feet per second (as above) multiplied by the area of opening in square feet, and by 6·20 = Gallons discharged per second.

To estimate approximately the Velocity and Discharge of a Running Stream:—

To measure the Velocity the readiest method is to select a piece of straight and unobstructed run of the stream, measure, and peg off, say, 100 or 150 ft. on the bank, in the direction of the flow of the water. Start a "Float" (which may be a small block of wood, or a cake of wax, or a bottle partially filled and corked) at as near the middle of the stream as possible and at a little distance above the Measuring Stake. Then by the seconds hands of a watch note the time in seconds that the Float occupies in passing the measured distance.

This distance in feet or in inches, divided by the number of seconds occupied by the Float in passing over it, will give the greatest Surface Velocity in *feet* or in *inches* per second.

In small shallow streams the Velocity so obtained should be fairly correct as a measure of the velocity of the whole stream, but if the stream is deep (say half the width or more in depth), then the Greatest Velocity would probably be at about $\frac{1}{3}$ of its depth, and to accurately observe this the Float should be so weighted as to travel at that depth, a projecting "mast" being arranged to show above the water level.

Then

$$\left.\begin{array}{c}\text{The Velocity}\\ \text{in seconds}\end{array}\right\} \times \left\{\begin{array}{c}\text{Area of section of}\\ \text{stream in sq. ft.}\end{array}\right\} = \begin{array}{c}\text{Discharge in}\\ \text{Gallons per second.}\end{array}$$

Rules.

To find Discharge—

Area × *Mean Velocity* = Discharge.

To find Area—

Discharge ÷ *Mean Velocity* = Area.

To find Mean Velocity—

Discharge ÷ *Area* = Velocity.

Note.—All terms may be in inches instead of feet, and all terms may be in minutes, or hours, instead of seconds.

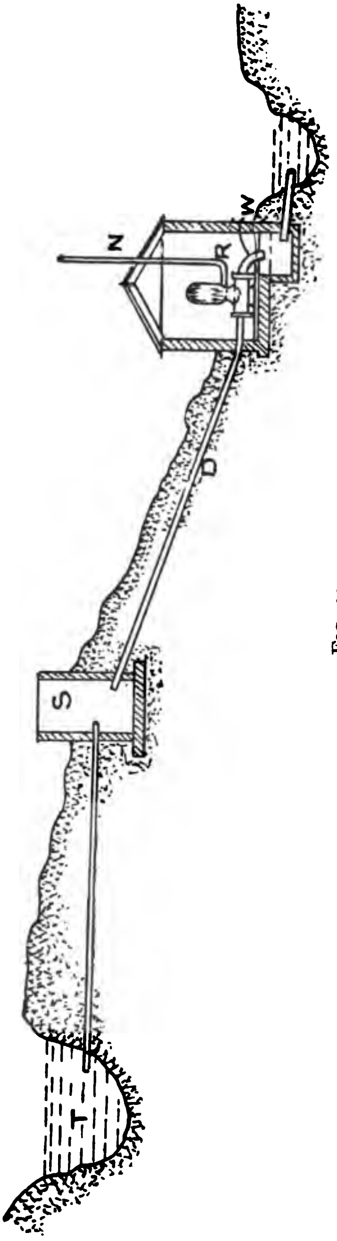


FIG. 33.

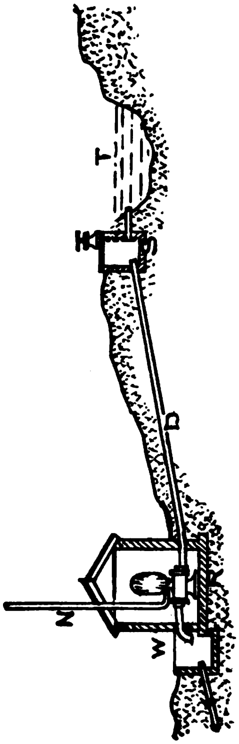


FIG. 34.

To estimate the H.P. of falling water—

$$\frac{\text{Cubic feet per minute} \times \left\{\begin{matrix}\text{Vertical height}\\ \text{of fall in feet}\end{matrix}\right\} \times 62{\cdot}5}{33{,}000} = \text{H.P.}$$

Example.—Over a fall of 16 ft. in vertical height 800 cub. ft. of water is discharged per minute, required the H.P.

$$\frac{800 \times 16 \times 62{\cdot}5}{33{,}000} = 24{\cdot}25 \text{ H.P.}$$

Before leaving the subject of Hydraulic Rams it may be well to state that they possess one disadvantage in that there is a certain amount of shock and noise incident to the closing of the valve C. If the closing of this valve be retarded too much in attempts to diminish the shock, the efficiency of the machine is impaired through the loss of too much of the energy of the flowing water. In the smaller sizes of machines, say up to 3 in. or 4 in. diameter of Drive pipe, this shock is not so great as to cause special inconvenience. In larger sizes of the apparatus an extra air chamber and air valve are introduced by some makers, with other additions designed to overcome the above-named objection. Such Rams are now frequently constructed of such size as to require 2 ft. diameter pipes, and are made to work with great smoothness and absence of shock.

Figs. 33, 34, show an ordinary arrangement for the installation of a Hydraulic Ram, although it need hardly be said that very many modifications of same may be adopted to suit circumstances.

In these illustrations, R is the Ram, S the supply Reservoir fed from River or Stream T, D the Drive pipe to supply water to the Ram, W the waste or overflow pipe, N the delivery pipe.

CHAPTER X

WATERWHEELS

THE various appliances for developing and communicating the power of falling water are too numerous to admit of detail within the limits of these notes, but it will be well to give some attention to the two most ordinary methods of utilisation of such power, viz. " Waterwheels " and " Turbines."

Referring to the remarks made in previous chapters, it will be noted that in general bearing they refer to water confined in Pipes or Closed vessels. In dealing with the subject of Waterwheels, it is necessary to take into account the effect produced by water falling freely, and unconfined by trough or pipe, upon " Floats " or Buckets fixed upon the periphery of a wheel, and to ascertain this it is essential to have regard to the " Law of Falling Bodies." In this connection the Table given below will be of assistance, showing that it is requisite to use as data the Space fallen through, and the Time occupied in falling through that Space, to find the Velocity acquired by the falling body :—

Space Fallen through in Feet.	Time of Falling in Seconds.	Velocity Acquired at the End of the Time, per Second.	Space Fallen through during the *last* Second of the Time.
16 feet	1 second	32 feet	16 feet
64 "	2 "	64 "	48 "
144 "	3 "	96 "	80 "
256 "	4 "	128 "	112 "
400 "	5 "	160 "	144 "
576 "	6 "	192 "	176 "
1024 "	8 "	256 "	240 "
1600 "	10 "	320 "	304 "

Given the items of the Space fallen through, and also the Time occupied in its falling through that space; this resolves itself into the following formula:—

$$\left.\begin{array}{c}\text{Square root of the height}\\ \text{fallen through}\end{array}\right\} \times 8 = \textit{Velocity acquired per second.}$$

Thus, it is required to find the Velocity of a Body Falling from a height of 80 ft.

Rule.—Multiply the square root of the height by 8.

Example.—(Referring to Table of Square Roots) $\sqrt{80} = 9$.

$\therefore\ 9 \times 8 = 72$ ft. velocity per second.

It is required to find Velocity of a Falling body when the *time* is given. Say time 6 secs.

Rule.—Multiply the time in seconds by 32.

Example.—$6 \times 32 = 192$ ft. per sec. Velocity acquired.

Or, knowing the *Velocity*, what *Time* is taken in falling?

Rule.—Divide the Velocity by 32.

Example.—The Velocity $= 72$ ft. per sec.

$$\frac{72}{32} = 2{\cdot}25 \text{ secs.}$$

Or, having the Velocity, to find the *height* of the fall.

Rule.—Divide the Velocity by 8, and the square root of the product = Height of fall.

Example.—The velocity, 72 ft. per sec.

$$\frac{72}{8} = 9, \text{ and } 9^2 = 81, \text{ which is the Height of the fall in feet.}$$

A Weight takes a certain number of seconds to fall; required to find the *space fallen through in the last second of time.*

Rule.—Multiply the number of seconds by 2, and by 16, and subtract 16 from the sum = space fallen through in the last second of time.

Example.—Say time in falling 2·25 secs.

$$2{\cdot}25 \times 2 \times 16 = 72,$$

and $72 - 16 = 56$ ft., the Space fallen through in the *last* second.

The height fallen through by a *certain weight* being given, what time will it take in falling?

Rule.—Divide height in feet by 16; the square root of the product gives the time in seconds.

Example.—Say the height fallen through is 80 ft.

$$\frac{80}{16}=5$$

$$\sqrt{5}=2{\cdot}236.$$

The time in seconds taken by a weight in falling, to find the *space fallen through.*

Rule.—Square the time in seconds, and multiply by 16, gives the space fallen through.

Example.—Time, say, 2·25 secs.

$$2{\cdot}25^2=5{\cdot}06,$$

$$5{\cdot}06\times 16=80 \text{ ft., the space fallen through.}$$

Now, in considering the question of the Mechanical energy of Water, when brought to bear upon any Hydraulic Motor, it is necessary to take as factors the Velocity at which the stream is brought into action, the Pressure, due to the height of its fall on, or into, the machine, and the Elevation at which it is brought to bear, relative to the point of Escape after its work is done. The less the energy of the escaping water, relative to its original capability, the more efficiently has it been made use of.

A machine may be worked by any one of the Factors enumerated, by Velocity of the water, by the Pressure due to its Head, or by its Elevation (as above defined). Or a combination of such factors may be developed in a machine. It should always be borne in mind, when wishing to obtain Mechanical results with the maximum economy, that the greater the *Head*, the greater the *Velocity* of the water, and the greater the velocity of the water, the *less* the *quantity* required for a certain H.P.

Waterwheels, though old-fashioned, may still be frequently used with advantage in many situations, though it cannot be claimed that they are less costly in construction than other Water motors of greater efficiency.

The ordinary varieties of Waterwheels are:—

Overshot Waterwheels.	See fig. 38.
Breast „ „	See figs. 36 and 37.
Undershot „ „	See fig. 39.

The approximate Relative Efficiency of these may be taken as under, theoretical power being 1·00:—

Overshot Wheel, ·68. Breast Wheel, ·55 to ·60.
Undershot Wheel, ·35. Poncelet Wheel, ·60.

So it is obvious that, where circumstances admit, it is more advantageous to employ an Overshot Wheel than either of the others, since the degrees of efficiency noted above refer to Wheels of uniform diameter.

As a Wheel of any kind properly constructed is *balanced* upon its Axle, the force required merely to turn the Wheel would only be that necessary to overcome the friction of the axle in its bearings. Of course, it follows that the *lighter* in construction the wheel may be, the less the friction.

Since the Water falls *freely* upon the periphery of a Waterwheel, a large percentage of the energetic force of the water is liable to dispersion by splashing, and especial attention should therefore be given to making the buckets of the Wheel of such shape as may best retain the water falling upon it, and utilising the weight of such body of water as long as it can be retained on the descending side of the Wheel.

The Weight of the water, after previous explanations, may be readily ascertained in any given case.

The illustrations given on pp. 78–80 will serve to elucidate this subject.

Fig. 35 shows what is ordinarily termed a "Floating Mill Wheel," and is so designated, because some of the "Floats" A A A are partially submerged in a Running stream, the impetus of which brings force to bear upon the Wheel. Such wheels are usually constructed about 12 ft. to 15 ft. in diameter, and have from 9 to 12 floats, the wheel being about 2 ft. to 2 ft. 6 in. in width. It should be so hung that not *less* than 2 Floats are immersed in the water at once, to about one-half of their depth. The velocity of such wheel should approximate half the velocity of the Stream.

"Undershot" Waterwheels are arranged somewhat in the manner above described, but have a larger number of angular or curved Buckets, instead of the Floats, and are worked by a Stream of water to which a slight fall has been given by damming the water above the Wheel to some extent, giving it a somewhat greater Velocity than that of the Supply stream. Such wheels are usually constructed 10 ft. to 20 ft. in diameter, and used for falls up to about 6 ft. The thickness of the entering stream of water should not exceed 10 in. As in these Wheels the Momentum of the water alone is utilised, their ratio of Efficiency is not high, being usually about ·30 to ·35 of the actual power.

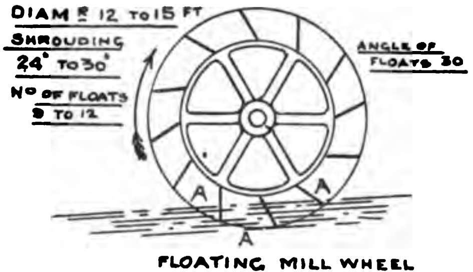


FIG. 35.

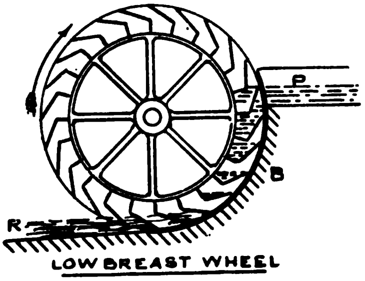


FIG. 36.

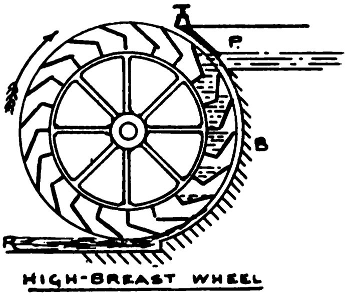


FIG. 37.

Fig. 36 illustrates the arrangement of a "Low Breast" Waterwheel, in which the Water is brought to bear upon the

Wheel on the side nearest to the Sluice, reaching the Buckets at a point coincident with, or below, a horizontal line taken through the Centre of the Wheel.

Such "Wheels" are used for falls as low as 6 ft. or 8 ft., being about 15 or 16 ft. in diameter. The distance between the Buckets should be 9 in. to 12 in., and the depth of the shrouding about 16 in. Efficiency about ·50 per cent. to ·55 per cent.

Fig. 37 shows the arrangement of a "High Breast" Wheel, in which the water is led on to the wheel *above* its horizontal centre line, thus utilising the Weight of the water through a greater extent of fall than in the case of the Low Breast Wheel. The increased efficiency of the former amounting to about 5 per cent. to 8 per cent. for the same size of wheel. The distance between the Buckets should be 6 ins. to 8 ins., and the depth of shrouding about 12 ins

An approximate rule for finding the number of Buckets is :—

Wheels 12 ft. to 25 ft. diam.	Diam. × 2·1 =	No. of Buckets.
" 25 " " 40 " "	" × 2·3 =	"
" 40 " " 50 " "	" × 2·4 =	"

In "Breast Wheels" the Water acts by its Weight alone, dropping into the Buckets almost vertically; they should therefore be set in a pit or "Race," with the Apron or Breast B curved to fit as closely as practicable to the periphery of the wheel and thus prevent undue waste of water. The Penstock P should also fit the wheel as closely as possible.

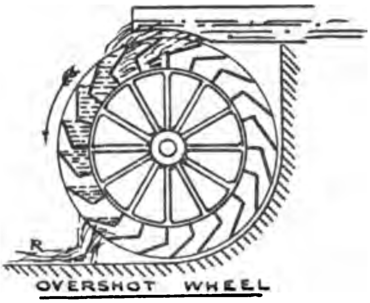


Fig. 38.

The illustration (fig. 38) shows an "Overshot Wheel," where the stream is led on to the Wheel at the top in such manner as to make the fullest use of the weight of the water in its descent from N to P, and, to a small extent, also utilises some portion of the Impulsive power of the Stream.

As this arrangement allows of a greater Depth of Fall than in a Breast Wheel, as well as taking some advantage of impulsive force, it is obvious that the ratio of efficiency is much larger than in the case of Undershot or Breast Wheels.

This type of Wheel is used for falls of 10 to 70 ft., with Head-water level varying not more than 2 ft.

It is desirable that the water should have a greater Velocity than the periphery of the Wheel. Presuming the latter to be 6 ft. per second, the former should be about 10 ft. per second. This is the velocity acquired by Water falling through a height of 1·5 ft., so that it should enter the wheel at a point that distance below the level of the surface of the "Head" water.

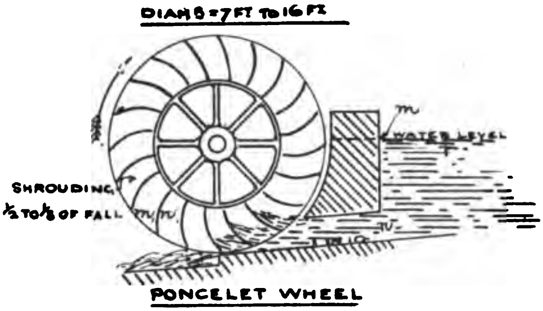


FIG. 39.

The diameter of the wheel may be arranged for any fall up to, say, 70 ft.

Depth of Shrouding = 10 to 18 ins.

Number of Buckets = Circumference ÷ Depth of Shrouding.

The water supplied to the wheel should not exceed about ⅓ of the Capacity of the Buckets directly under the sluice opening, otherwise there may be considerable loss of water by spilling.

Fig. 39 is a sketch of a modification of the "Undershot Wheel," where the stream flows on to the Floats through a Sluiceway at bottom of a Mill dam. The "Floats" or "Buckets" in such Wheel being suitably curved, it may be made to yield an efficiency as great as that of a High Breast

Wheel. This arrangement is known as the "Poncelet" Wheel.

Since it is evident that water falling into Buckets of a Waterwheel is liable to a considerable amount of waste by Splashing, and that every economy in this respect adds greatly to the efficiency of a Waterwheel, the question of so proportioning and shaping the Buckets as to minimise this loss is an important one, as is also that of retaining the water on the Wheel as long as it can produce useful effect. With this end in view, the Buckets are shaped as a series of Troughs, constructed in wood or metal, and of shape somewhat as shown in fig. 40, and so arranged and spaced that each Bucket comes into place for filling just at the time its predecessor has gone forward loaded.

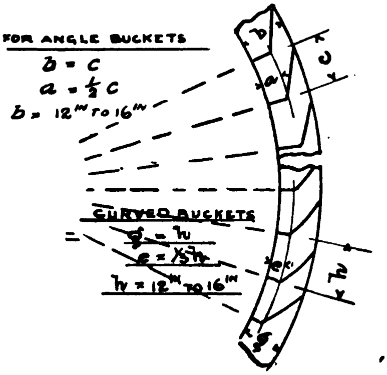


FIG. 40.

The supply should be so regulated by Sluices that only sufficient is passed on to the Wheel to keep the Buckets filled, or only partially filled, as may be required.

EFFECTIVE H.P. OF WATERWHEELS

Undershot Waterwheel—

Quantity of water in cubic feet per second	× Head of water in feet	× ·00066 =	Effective H.P.

Low Breast Wheel—

Quantity	× Head	× ·00104 =	"

High Breast Wheel—

Quantity	× Head	× ·0013 =	"

Overshot Wheel—

Quantity	× Head	× ·00128 =	"

Velocity of "*Breast*" and "*Overshot*" Wheels—

Height of Fall.	Velocity of Wheel Periphery per Second.
5 feet.	7 feet.
10 „	6 „ 6 inches.
15 „	6 „ 2 „
20 „	5 „ 8 „
25 „	5 „ 4 „
30 „	5 „ 0 „
40 „	3 „ 8 „
50 „	3 „ 4 „

To ascertain the *Velocity* of the *Stream of Water* in feet per *second* or per *minute.*

$\sqrt{\text{Head}}$ in feet × 8·025 = Velocity of stream in feet per second.

$\sqrt{\text{Head}}$ × 481·5 = Velocity in feet per minute.

See also Table IX.

In respect to the Conveyance of the Power from the Wheel to the Machinery which it is intended to operate thereby, this may be accomplished by a Crank keyed upon the shaft of the wheel, or by Gearing, or by Pulleys and Belting, as may be most convenient, and in this connection a few simple Rules for proportioning same may be found serviceable.

In the case of a Crank: Suppose the diameter of the Wheel to be 12 ft. (radius 6 ft.) and the Crank E 18 ins., then the effective work of the Crank would be that of a Lever of which the radius would be the longer arm and the Crank the short arm, the Power being applied at the periphery of the wheel.

PROPORTIONING PULLEYS

The number of Revolutions of a Wheel per minute, being multiplied by the diameter of the pulley on its shaft, and divided by the number of Revolutions required on the driven machine = The required diameter of Driven pulley, or thus :—

To ascertain diameter of "Driven" wheel—

As the required No. of Revs.	:	The diam. of Driving pulley or wheel	: :	The diam. of Driving pulley	:	The required No. of Revs. of Driven pulley.

To ascertain number of Revolutions of Driven pulley—

As diam. of Driven wheel	:	No. of Revs. of Driving pulley	: :	Diam. of Driving pulley	:	Required No. of Revs. of Driven pulley.

If the power is first conveyed to a Countershaft and thence to the Machinery to be operated, find the proportions as under:—

The shaft of a machine A (fig. 37) is required to run at a certain number of Revolutions, when driven through a Countershaft C, by a Motor-shaft B running at a certain speed; then

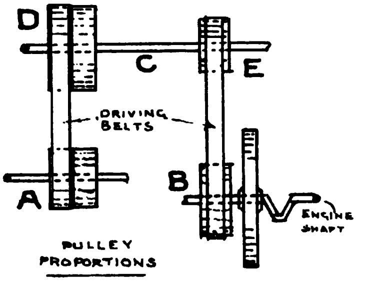
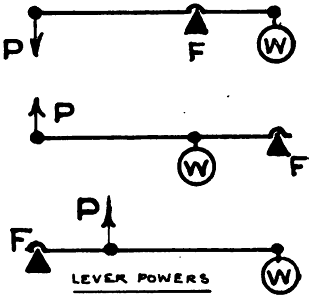


FIG. 41.



FIGS. 42, 43, and 44.

To find diameter of pulley D—

$$\frac{\text{Revolutions of A} \times \text{Diam. of A}}{\text{Revolutions of C}} = \text{Required diam. of D.}$$

To find diameter of pulley A—

$$\frac{\text{Diam. of D} \times \text{No. of Revolutions of D}}{\text{Required No. of Revolutions of A}} = \text{Required diam. of A.}$$

To find diameter of pulley E—

$$\frac{\text{Diam. of B} \times \text{No. of Revolutions of B}}{\text{Required No. of Revolutions of E}} = \text{Required diam. of E.}$$

LEVER POWERS.

Lever of First kind (see fig. 42).

F is the Fulcrum. W is the Weight. P is the Power.

$$\frac{\text{W} \times \text{Distance FW}}{\text{Distance WF}} = \text{The Power required at P to balance W.}$$

Lever of Second kind (see fig. 43).

$$\frac{P \times \text{Distance P.F.}}{\text{Distance P.F.}} = \text{The Power required at P to balance W.}$$

Lever of Third kind (see fig. 44).

$$\frac{W \times \text{Distance W.F.}}{P} = \text{Distance P should be from F to balance};$$

and

$$\frac{P \times \text{Distance P.F.}}{W} = \text{Distance W should be from F to balance.}$$

To ascertain the mechanical advantage of Sheaves:—

Weight to be raised—

Number of movable pulleys × 2 = power.

The number 2, multiplied by itself as many times as there are movable pulleys, will give the mechanical advantage or the relation of power to weight.

CHAPTER XI

TURBINES

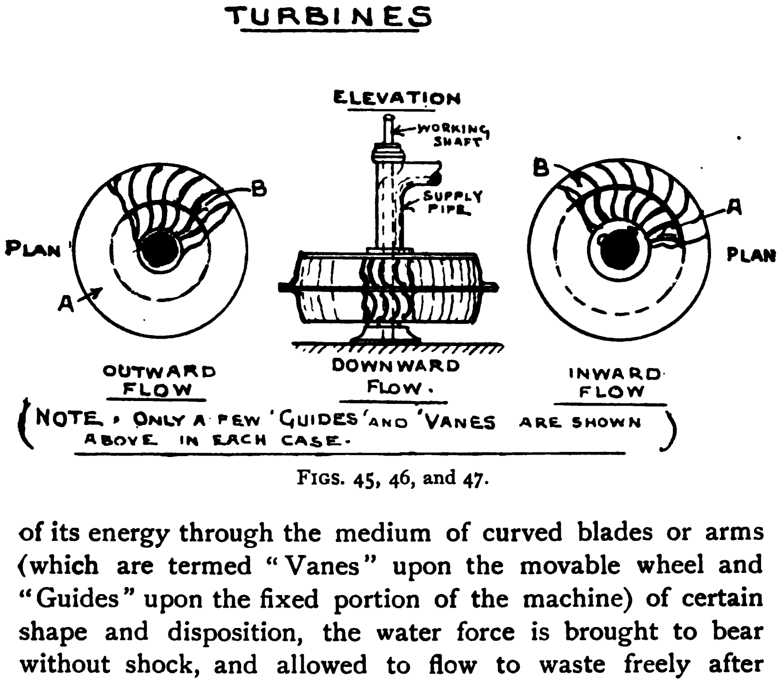
TURBINES may be said to be an evolution of the Waterwheel. The large size and cumbersome nature of the latter, though not always a detriment (since they may be used to advantage in situations where the installation of a Turbine would entail too great a cost in importing and erecting same) in every sense, still renders the use of the former advantageous in very many cases.

There are very numerous varieties of Turbines, adaptable to as many conditions of work, and hence the selection of the machine for specific work is a matter requiring a considerable amount of care. Indeed, the considerations which should govern such selection are so numerous that it is not possible to do more in such a short treatise as this than give some few data that may serve as a guide to intending users.

In general terms it may be stated that, whereas in the Waterwheel the latent power of the Water is brought into action by utilising its *free flow*, the Turbine is a machine designed to obtain greater effect from water in Confinement. Since a running stream of water possesses ordinarily three elements of energy, viz. its Velocity, its Pressure due to its *Weight*, and its Pressure due to its *Elevation* Head, it must be evident that any machine which will utilise all three of these will prove the most efficient motor.

As already pointed out, the " Elevation " head is well made use of in the old-time Waterwheel, driven by causing the water to flow on to a Wheel, and falling from an elevation to a lower level. But to make use of the "Pressure" Head, the water should be confined in such manner that the force due to its "Head" shall be *concentrated* upon the machine it is intended to move. In the Turbine this object is attained by directing the flow of the water upon the Blades or Arms of a Wheel confined in a casing, surrounding a central fixed distributing medium, or by a modification of the two, the power developed being taken off the machine by gearing or shafting.

By confining the Power water and directing the course of its energy through the medium of curved blades or arms (which are termed "Vanes" upon the movable wheel and "Guides" upon the fixed portion of the machine) of certain shape and disposition, the water force is brought to bear without shock, and allowed to flow to waste freely after expending such force. A very large proportion of its useful effect is utilised, giving an efficiency of 75 per cent. in a well designed machine, and occasionally as high as 80 per cent.



FIGS. 45, 46, and 47.

It may be said that a "Turbine" is really a "Centrifugal pump" reversed, and having Guides to direct the water in its course as it enters the wheel.

The machines are constructed for applicability to falls varying from 5 or 6 ft., to several hundreds of feet, modifications of design being introduced according to the work. When used for very low falls, the machine may be immersed in a "Tank" or "Flume," whilst for higher falls (say over 15 ft.) the water is led in pipes to a Casing surrounding the machine (see illustrations, figs. 45, 46, and 47). They are constructed to work with the wheel in either a Horizontal or a Vertical position, according to requirement, the vertical position being the least used.

The varieties of "Turbines" principally differ in the arrangements adopted for changing the Direction in which the water flows through the Turbine, the controlling and regulating of the Water supply, etc. They may, however, be classed under three general types, viz.:—

Outward Flow Turbines,
Inward Flow Turbines,
Downward Flow Turbines (a combination of the above),

and these, again, may be classed as "Radial Flow," and "Axial Flow." It should, however, be understood that these classifications arise rather as matters of convenience to suit certain conditions, without involving any material difference of action. Some Turbines are so constructed that *all* the passages in the machine require to be *entirely filled* by the water, and this kind (known as "Pressure Turbines") may be worked most advantageously when *submerged* altogether in the Tail water.

Another description, called "Impulse Turbines," are so arranged that the water is passed through the passages of the Wheel without entirely filling them. These must be so fixed as to discharge always *above* the "Tail race," and may be worked by varying degrees of pressure as desired.

Since "Impulse Turbines" will not work when "drowned," they should not be adopted if the Tail water is liable, under any circumstances, to rise to the level of the Machine. "Pressure Turbines," on the other hand, work *best* under water, but if such disposition is not convenient, they may be fixed at ***any height,*** less than about 22 or 23 ft. ***above*** the Tail race, and the waste carried away in a pipe to the "Race." The "Pull," caused by the flow of this discharged water tells as Power, so that the effect of the "head" may be estimated as due to the ***total height*** from "Tail Race" to "Inlet."

If the water supply should not be full and constant, Impulse Turbines are most suitable, as this kind more readily admit of regulation according to the supply. They are also best if the height of the "fall" is great (say in excess of 40 or 50 ft.). With ample supply and moderate "Fall," Pressure Turbines will give the greater satisfaction.

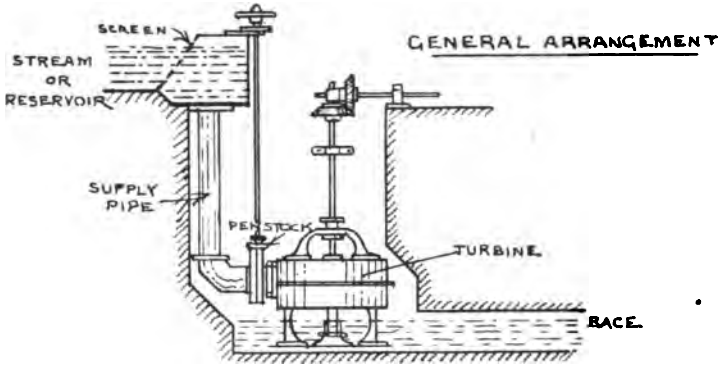


FIG. 48.

The illustrations figs. 45 to 48 will serve to explain some of the points of difference in the arrangements of the classes of Turbines, but space does not admit of giving any full details. The following letters of reference will define the parts of the Machines:—

(In all cases A A refers to the fixed portion of the machine, and B B to the moving part.)

C is the Delivery pipe to the Turbine.

The Fixed curved Blades are called "Guides," and lettered G. The Moving Blades are termed "Vanes," and lettered V.

WATER REQUIRED PER H.P.

Head in feet	30	40	50	60	70	100	
Cubic feet per H.P. per second	·39	·29	·23	·20	·15	·117	Efficiency ·75
Do.	·37	·28	·22	·18	·14	·11	·80
Velocity of periphery in feet per second.	26	30	34	37	43		

Table X. (page 115) gives some useful data relative to "Downward Flow Turbines."

The following Rules will also be found of service in any calculations relating to Turbines:—

The *velocity* of the Periphery of the Wheel varies from ·55 to ·60 of the Velocity due to the "Head," the latter being given in Table IX.

The number of *Revolutions* per minute may be found approximately by dividing 10 *times* the velocity of the periphery (as above) by the *Radius* of the wheel.

It should be noted that, although the *speed* of the Wheel of a Turbine is dependent upon the Velocity of the water, the *diameter* of the Wheel may be selected so as to give any *required number of Revolutions.*

Of the same genus as Turbines, are "Tangent Wheels," which are very serviceable for many classes of work where a high rate of speed is desirable, and a considerable Water pressure is available. In such wheels the water is brought to bear upon curved "Buckets" or "Vanes" at a tangent to the periphery of the wheel, the arrangement being somewhat as shown in fig. 49. In such machines the pressure water can be regulated by an adjustable Sluice as shown, or by a stop-valve.

Very careful attention should be bestowed upon the construction of the "Race" or "Flume" used to conduct the water to, or from, a Turbine, and it is, as a rule, desirable to arrange same so that the water should not travel faster than about 90 ft. per minute. Provision should always be made for the prevention of foreign matter passing to a Turbine with the Power water.

There is no Turbine of any make or class equally adaptable to all conditions of Quantity and Fall; hence it is always desirable to afford all possible information to the makers when ordering, and, whenever possible, by sending a sketch showing the proposed site for the Turbine, and its relation to the machinery it is required to drive.

The following data should always be supplied:—

The purpose for which it is designed to use the "Turbine."

What "Head" of water there is available (*i.e.* the vertical distance from the surface of the water destined to supply the Turbine, to the lowest level to which it can fall and flow away freely).

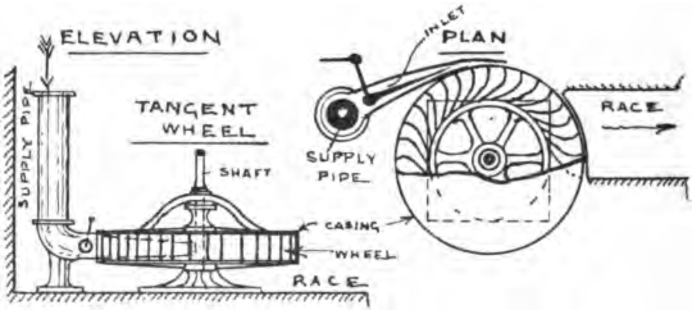


FIG. 49.

The Quantity of water flowing per minute that can be depended upon.

The particular speed at which it is essential that the shafting should be run.

To ascertain how much Power is available from a Stream, the flow of which has been gauged:—

Multiply the number of cubic feet of water per minute by 62·5 (the weight in pounds of 1 cubic foot of water), and this again by the height of the fall in feet, which will give foot-pounds. Foot-pounds ÷ 33,000 = H.P.

With the best proportioned and constructed Turbines, 75 per cent. to 80 per cent. of this result should be taken as the useful effect that can be obtained.

Note.—I need not point out that in this matter of Turbines it does not come within the scope of this work to deal with the application of "Steam" to the usage of the Turbine; as the present treatise refers only to its adaptation to Water Power.

CHAPTER XII

PELTON WHEELS

THE "Pelton" Waterwheel is a Direct Pressure Wheel, and is more especially intended for use under a force of water due to a considerable "Head," being rarely used for heads of less than 50 ft., but frequently put to work under heads of even over 1000 ft.

The diameter of the Wheels themselves vary from 6 ins. to as many feet, but the power of the wheel is less dependent upon its diameter than upon the head and quantity of water brought to bear upon it. For a considerable head a small wheel only could have been requisite, whilst for low heads, with fairly large quantities of water, a much larger wheel may be advisable.

The Wheels are fixed in a vertical position upon a horizontal shaft, and either with or without any casing or Wheel Race. The force of the water is brought to bear upon the wheel through the medium of small jets (one or more in number, as may suit circumstances) delivering at a tangent to the periphery of the Wheel, into Cups or Buckets attached to the outside of the rim of the Wheel. Much of the efficiency of the machine depends upon the shape, number, and proportion of these buckets, and the size of the Jet must be selected proportionate to the quantity of water, the height of the fall, and the diameter of the wheel and its required speed.

The speed of the smaller wheels may vary from 800 to 2000 Revolutions per minute; with the larger sized wheels, 150 Revolutions to 300 Revolutions per minute.

A Wheel of this type may be adapted to different conditions of Water supply without loss of useful effect, by exchanging a Nozzle of one size for a larger or smaller one, as the case demands; for an increase of supply using a larger nozzle, a smaller one being substituted for a diminished supply.

It should always be borne in mind that the Quantity of water requisite for developing a given Power decreases in direct ratio as the "Head" pressure increases.

Where considerable head of water is available with a constant flow, the "Pelton" Wheel constitutes a very cheap and efficient motor. It is readily fixed, and easily kept in repair, being very simple in its construction, and it may be worked either by clean or dirty water impartially.

This class of wheel has attained much greater fame in America than elsewhere, but it is likely to be much more largely used as its merits become better known.

"Turbines" are doubtless the more desirable class ot machines for use of moderate heads, say to 80 or 100 ft., if the water is clean, but for heads above those named the "Pelton" Wheels offer the best medium of power production, considering their simplicity, and cheapness, and facility of erection.

As evidencing the small cost of these motors, it may be mentioned that the first cost of a "Pelton" Wheel, fitted in Casing, with Nozzle and Stop-valve, the whole contained on iron Bedplate and requiring only pipe connections, etc., capable of developing about 6 H.P., with a 200-foot head of water, is only about £25, the weight being about 3 cwts.

Fig. 50 is a sketch showing the general arrangement of a "Pelton Wheel," and the shape of the Cups or Buckets.

The Jet of water impinges upon the division plates of the Cups, and after exerting its useful effect, flows off from the sides of the cups into the waste-water channel below the machine, having parted with nearly all its energy before leaving the cups.

The power of a small Wheel can be increased by using two or more nozzles, disposed one above the other, and delivering on to the same wheel, a greater amount of pressure water being thus brought to bear. Such arrangement, moreover, admits of regulating an Intermittent flow, since by shutting off one or more of the Jets, the speed of the wheel may be maintained; of course, its power is necessarily diminished as each Jet is closed, although its "ratio of Efficiency" may be unimpaired.

It is not needed to detail the purposes to which this class of motor may be applied, since it is suited to driving any kind of machinery, and where circumstances admit, it may even be coupled directly to the shaft of the Apparatus it is intended to operate, being frequently fixed upon the same Shaft, as in an Electric Dynamo, for instance.

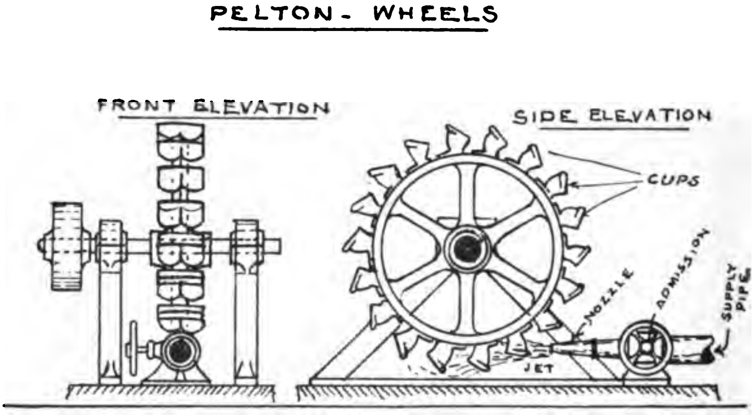


FIG. 50.

When making Inquiry or Ordering from the makers of these machines, such items of information should be given as follows:—

The amount of Water available, in gallons per minute.

The greatest "Head" of water available.

The Power required or purpose required for.

The Approximate length of piping, and size of same, both horizontal and vertical, from the source of supply to the proposed site.

Whether wood or iron framing is desired, and whether wheel Casing is required.[1]

If possible a dimensioned sketch of the proposed location of the machinery should be sent.

Of course, it will be fully understood, from the consideration of previous Chapters upon the subject of Measurement of supply, Friction of water in pipes, and methods of laying pipes, etc., that great care should be given to these points, when deciding upon Installation of such apparatus as the foregoing.

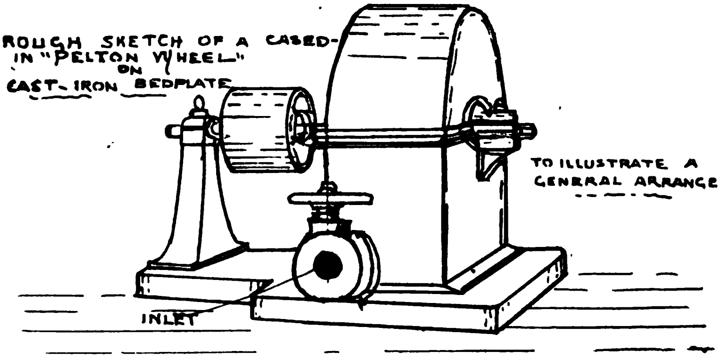

ROUGH SKETCH OF A CASED-IN "PELTON WHEEL" ON CAST-IRON BEDPLATE
TO ILLUSTRATE A GENERAL ARRANGᴱT
INLET

FIG. 51.

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[1] Wheel Casing is not a necessity ; it may be constructed in Wood or Metal, and its usage should depend upon the Conditions of the Work.

If the Installation is out-of-doors and exposed to weather, then a wood " Frame " and Wood " Casing " may meet requirements.

If in a Building, it would be more desirable to use a Metal " Casing " and Metal Bedplate, etc.

Fig. 51 is a sketch of a Pelton Wheel in an Iron Casing.

CHAPTER XIII

HYDRAULIC PRESSURE ENGINES

WHILST dealing with the subject of Water-driven Motors it will be well to call attention to a few of those machines other than "Waterwheels," and "Turbines," designed for the conveyance of the energy due to falling water confined in pipes.

These may be generally classed under the above heading, and embrace engines having pistons of varied shapes, deriving motion from the "Head" pressure of columns of water brought to bear upon them. Such engines are, as a rule, of large size (and, consequently, of high cost), in proportion to the work they are designed to perform. Still, they possess exceptional advantages in cases in which a Slow, Steady, and Strong power is required. With engines of this class a very great pressure can be utilised, especially in application to Cranes, Lifts, etc.,[1] and the easy governance of such engines, in combination with the great power they can develop, is such that in many cases it is desirable even to use Pumping power to produce the requisite Working pressure.

Small "Rotary" engines working under moderate pressures are often found very useful, and even economical where considerable Intermittent power is in requisition. The principal drawback to engines of this class are, considerable first cost, and somewhat extravagant usage of fluid energy, inasmuch as such engines require as great an amount of

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[1] As instancing the adaptability of such Motors—they are largely used, also, for providing Power for "Organ Blowing," where Water-pressure is available.

Pressure fluid to work them, whether they are developing full or partial power. Thus, they will develop approximately ·80 of the Water power when doing *full work*, but only about ·40 or ·50 when giving off half-power.

The most ordinary form of "Water-pressure Engine" is of the "Oscillating" type, and so constructed that through the agency of a Fly-wheel the Cylinder itself is made to perform the work of Admission and Release of the Power fluid.

The Velocity of the piston in such engines is usually about 60 ft. per minute.

The diameter of Water-supply pipe to the engine should be ·4 of the diameter of the Cylinder for a single-cylinder engine.

A variation of the mechanical arrangement of such engines is obvious, as any number of such Cylinders may be arranged side by side, or in pairs (one on each side of the crank shaft).

Hydraulic Rotary Engines are of so many designs that it is not necessary to attempt a description of them, but, as a rule, they take the form either of "Disc" or "Radial" pistons in a closed cylinder, operating a central shaft prolonged through the sides of the cylinder to carry a driving pulley or pulleys.

Engines of this type possess, to a certain extent, an element of simplicity, but also have the disadvantage of excessive "Slip" (which signifies the escape of Power water past the pistons without doing useful work), rendering them somewhat uneconomical.

Their *Convenience* as motors, however, in many cases may weigh against their inefficiency as *economical* machines, but it can only be in circumstances where a *variable* though *steadily certain* power has to be applied, irrespective of considerations as to waste water.

In the case of the Oscillating engines referred to above, the arrangement of the machine is such that very little friction occurs, and with an efficiency of, say, ·80 the friction in a fairly well constructed engine of this type does not exceed about 5 per cent to 6 per cent. At first sight this would appear improbable, since it would seem that the cylinder must press with such force upon the Valve face, in order to make a watertight joint, that there would be considerable friction. But here is evidenced one of the beautiful features of "pressure water." The surfaces being well fitted, the cylinder should be so balanced in its centres as to work quite freely on the Valve face, and when in operation it will simply oscillate upon an exceedingly ***thin film of Pressure water*** instead of rubbing metal on metal.

A splendid example of this use of the Pressure water is afforded in the powerful Turbines erected at Niagara Falls. These Turbines are placed down shafts 170 feet deep, and the Turbine wheels, Shafts, etc., weigh many tons, and revolve at a speed of 250 revolutions per minute. No mechanically constructed Footstep or Bottom Bearing could stand the strain, but by ingenuity in construction the whole weight is balanced by the great pressure of the water column itself. As the supply pipe to the Turbine is 7 ft. 6 ins. diameter, the total weight of water due to the head amounts to some 60 to 70 tons, and this is ingeniously utilised to support the weight of the Shafting, Turbines, Dynamo, etc., relieving the enormous pressure that otherwise would come upon the Footstep.

CHAPTER XIV

WELL BORING

SOME countries are so well favoured in the matter of Rivers, Streams, and Lakes, that it is only exceptionally that resort has to be made to the Sinking of deep wells, or for Boring for water supply. On the other hand, there are many lands where Rivers are infrequent and interrupted in flow, and surface water scarce. In some such countries (notably in the prairie countries of Western America) resort is largely had to the sinking of "Bore holes" to obtain water, and, little as surface indications frequently appear to justify the expectation, the results are, in the majority of cases, satisfactory.

In other countries where Surface water is scarce, and the lands are consequently unproductive, yet where indications exist of ample water supply below ground, either from ignorance or want of enterprise, few attempts are made to remedy by Boring for water. The cost of putting down "Trial Borings" in likely situations is not great, and in very many instances these "Trial Borings" may prove to be all that is required, since even in a 6-in. Bore hole it is quite possible to put a pump which would work satisfactorily at considerable depth. If a larger supply is required than such a pump could deal with, other borings can be made close by, or the original boring enlarged by "Reaming out" to take more powerful pumps.

"Artesian Wells" may be described as Borings from the Surface to tap Water lying in an underground basin upon an impermeable stratum of soil or rock. If such a Basin can be tapped by a Boring at or near to its lowest point, the water would rise in the boring to a height approximating its natural outlet, which would be the edge or Outcrop of the Stratum which retains the water. In many favourable situations the water will often flow out at the top of the "Bore hole," and sometimes with considerable force. Thus, the success of Artesian Well sinking is dependent upon the retentive nature of the water-bearing stratum, and upon the level of the escaping point of the water in such basin, which would be at Springs flowing from the upper edge of the stratum.

The quantity of water such Wells would yield is necessarily proportionate to the area of the containing Basin, and to its constitution as a retentive medium.

At best there must be considerable uncertainty as to results where "Artesian work" is undertaken, so much being dependent upon the configuration of the hidden strata. It follows that, when such work is in contemplation, it is the best policy to make the *first* borings of small size, as the proof being once established that water can be obtained in reasonable quantity, more extensive operations can then be confidently undertaken.

As the Boring tools, for anything less than a 6-inch bore, are necessarily light in construction, it is best to first bore to the depth for which such apparatus is suited, say a 4-in. or 6-in. diameter Bore hole. If it be found desirable to go deeper still, the bore hole may be "Reamed" out to, say, 6 ins., 8 ins., 12 ins., or even larger, as requirements may suggest.

Up to quite recent times the ordinary practice has been—when searching for an underground water supply—to dig Wells of considerable diameter (4, 6, or 8 ft.) and to protect the sides by brickwork, etc., carrying on such work until the water is met with, or failing that, abandoning what may have proved a costly experiment. Such methods may now be said to be well nigh obsolete, and, in the light of more Scientific knowledge, it is best that it should be so, since it can be a matter of little question that wells sunk as above referred to have often proved to be ready disseminating mediums for disease. In such Wells any percolations of surface Drainage or Sewage may find its way into and contaminate the water supply, although such supply, in itself, may be quite pure.

In a multitude of cases water can be obtained by the use of "Driven Wells" (known also as "Abyssinian Tube Wells"), when a supply may be tapped at within "Suction distance" (vertically) of the surface of the ground. Such "Wells" are exceedingly simple and far from costly. A wrought-iron Tube, of from 1¼ in. to 3 ins. diameter, has attached to its lower end a Solid steel point, above which a number of small holes are drilled in the Tube itself to a height of 2 to 3 feet from its lower end. This Tube being driven into the ground by means of driving Tackle on the surface, to a depth of, say, 30 ft., a Pump of ordinary construction is attached to the upper end of the Tube, at the Ground level, and (presuming that water *has* been tapped) the Apparatus is ready for use. In case a supply has *not* been reached, the Tube can be withdrawn, if desired, and driven in another situation.

It need hardly be pointed out that such "Driven Tube Well" can only be put down in fairly soft ground.

When water cannot be reached by the above method, resort should then be had to "Bored Tube Wells," otherwise "Artesian Wells." Such Wells may be bored to great depths, and even when Water-bearing strata are struck, which may not be found to yield a sufficiently pure supply, this inflow may be shut off by putting down steel Lining Tubes, and the boring carried on to greater depths until purer water is reached.

When the supply level has been definitely ascertained, a Pump barrel may be sunk in the Tube (or may form even a part of the Casing Tube), to within the proper Suction distance of the Water-bearing strata, and the water pumped to the surface.

As above stated, it may often occur that when water *is* struck, it may rise in the Tube to the Surface, or within such distance thereof that the Pumping apparatus may be arranged entirely above ground level. Should, however, this not be the case, the Pump may be sunk within the Bore hole, and worked by a rod from the Surface Gear. If one Bore hole does not give a sufficient supply, others may be sunk near by to increase the yield instead of enlarging the first Bore.

So many varying conditions obtain in connection with Well Boring, calling for Special arrangements, that they cannot be dealt with in this brief reference. It may, however, be stated that, when a Well Boring has been commenced, it should not be readily abandoned, since most obstacles met with (such as Impure supply, Air-impregnated strata, Insufficient quantity, etc.) may be overcome if intelligently treated.

Although Bore holes are frequently sunk of 4 ins. diameter, the saving thereby effected is not so very material, and the advantages incident to a larger bore are sacrificed. A 6-in. diameter Bore admits of the use of more substantial Tools during sinking, and of the insertion of a Pump of more useful size and construction.

Referring to the Tools used for Well Boring, the main difference consists in the use of those operated by "Rope Tackle" and those worked by Hollow, or Solid, metal rods from Boring Tool to surface. The American system most in vogue (and certainly the leading method in Well-Boring America) for comparatively shallow bores is that of Rope Tackle. A set of Tools is called a "String of Tools," including the Bit, or Boring tool, which is a weighty Chisel-shaped tool with certain attachments for operating same, and connected to a steel wire rope. The length of the "String" when put together being from 20 ft. to 60 ft.

Thus, for boring a 6-in. hole, say, to 500 ft. depth, the "String of Tools" would be about 30 ft. in length, weighing some 1200 lbs., and the Overground gear, Rope, etc., about 3000 lbs. About 5 H.P. would be required to operate the Machine, and the cost of Apparatus (exclusive of Engine and Boiler, or other motive power) would be about £200.

The cost of drilling a 6-in. hole (varying, of course, as to locality) in nothing harder than Limestone would be from 20s. to 25s. per ft., or in hard rock about £2 per ft. Bores of 8 ins. diameter would cost about 25 per cent. more. For very *deep borings* heavier and more costly Apparatus would be required.

In the case of Solid boring rods being used, the cost of the Rods and Boring tools varies greatly according to the depth of the boring to be undertaken.

Thus a complete set of Tools for a 6-in. Bore to, say, 300 ft., with the Sheer-Legs and Gearing for operating the Tools, would be about £120. For 8-in. Bore to, say, 500 ft., £180 at Shipping port. This estimate is exclusive of any Motive power or of any Casing Tubes.

The cost of "Driven Tube Wells" with 30 ft. length of Tube may be taken approximately as under :—

1¼-in. Tube Well Apparatus, inclusive of common Lift Pump . . .	£7	0	0
2-in. Tube Well Apparatus, inclusive of common Lift Pump . . .	£9	10	0
3-in. Tube Well Apparatus, inclusive of common Lift Pump . . .	£15	0	0

The Driving apparatus, Sheer-Legs, etc., are not included in above, but would cost from £12 to £30 the set, according to size. It should, however, be pointed out that the Tubes may be driven by any "home-made" apparatus, and that a set of Driving Tackle need only be ordered in cases in which a *number* of Tubes have to be driven.

The yield of 1¼-in. Tube Well with constant supply, and a good pump, should be about

300	gallons per hour	for a	1¼-in.	Tube.
600	,,	,,	2	,,
1200	,,	,,	3	,,

It must be understood that the Prices given for cost of Apparatus, and Operating same, vary greatly, according to locality, and those named are simply intended as a Guide for approximate estimates.

NOTES RESPECTING HYDRAULIC POWER

There is little doubt but that ignorance of the capabilities of Hydraulic power, combined with the prominence given in the present day to newly developed adaptations of such powers as Electricity, Compressed Air, etc., have tended in a large measure to obscure the view of its possibilities. When studying the question of conveyance of power to a distance, for instance, an ordinary observer is apt to take note of the economical manner in which it can be transmitted, whilst losing sight of the fact that, before such agency can be brought to bear, it must be developed through the medium of some Extraneous power. Thus, in Electrical Machinery the production of the energetic current requires the aid of steam, Water, or other agency, in the first instance, but had this first *agent* been utilised in a manner consistent with well-known mechanical adaptations, its ultimate cost in usefully employed energy would in a vast number of cases be far more economical than its reproduction through a second medium.

This is no question of theory, since the proof has been so amply afforded in the installation of extensive works for the distribution of *Water Power* (leaving other powers out of the question) in Europe and in America.

To those who have made any study of the development of the power contained in a Body of water, it cannot but appear strange that in countries well watered by Rivers and Streams, so little effort is made to turn the latent power to good purpose. And even if the power is not developed, or not in actual demand, think of the millions of acres in "dry" countries which could be Irrigated at comparatively little cost, if the Landowners would but study their own interests.

A combination of the Owners of lands, or the foundation of a Company in certain districts, with the view of making use of their Streams and Rivers for Irrigation and Power purposes, would bring an immensely larger percentage of lands into profitable use and also yield Power to the proprietors at small cost to reduce the uncertainty and inefficiency of raw labour.

The foregoing Treatise should at least enable anyone desirous of making use of an Available Water Supply to form a fairly correct estimate as to the most efficient and economical method for so doing, or possibly of saving others from the expenditure of large sums simply in experiments which might lead to disappointment, if not conducted intelligently.

HYDRAULIC MEMORANDA

Weights and Measurements of Water

1	Cub. in.	Fresh Water	weighs	·0361	lb.
12	„ ins.	„	„	·434	„
1	Cyld. in.	„	„	·0284	„
12	„ ins.	„	„	·341	„
1	„ ft.	„	„	49·1	„
1	Cub. ft.	„	„	62·5	„
1	„ ft.	Salt Water	„	64·1	„
1·8	„ ft.	Fresh Water	„	1	cwt.
35·84	„ ft.	„	„	1	ton.
277	„ ins.	„	„	1	gal.
1	„ ft.	„	„	6·25	„
1	Cyld. ft.	„	„	5	„
1	Gal.	„	„	10	lbs.
11·2	„	„	„	1	cwt.
224	„	„	„	1	ton.
2·282	Cyld. ft.	„	„	1	cwt.
45·64	„ ft.	„	„	1	ton.

Multipliers

Cub. ins. × ·0036 = Gals.
„ ft. × 6·24 = „
Gals. × ·16045 = Cub. ft.
Cyld. ft. × 4·9 = Gals.

1 in. of Rainfall per acre = 22,620 gals.
1 „ „ = 101 tons.
1 „ per sq. mile = 14,500,000 gals.
1 „ „ = 64,630 tons.

Snow and Ice

Snow has about 12 times the bulk of water (fresh).
1 Cub. ft. of Snow weighs 6 lbs.
Water in freezing expands to the extent of 8 per cent.
1 lb. of Ice (at 32°) occupies 30 cub. ins.
1 Cub. ft. of Ice weighs 58 lbs.

Water Supply

Quantity usually allowed for—

Household supply per head daily	15 gals.
Hospital supply (per head)	30 ,,
1 Sheep requires daily	1 ,,
1 Ox ,, ...	8 ,,
1 Cow ,, ...	9 ,,
1 Horse ,, ...	10 ,,
Town supply, including sewer flushing, street sprinkling, fire purposes, factory use, etc., should not be less per head per day than .	30 ,,

Useful Rules

To convert English gallons into American gallons—

$$\frac{\text{English gals.} \times 10}{12} = \text{American gallons.}$$

No. of cyld. ins. in any circle—

Square the diam. of circle = cyld. ins.

No. of sq. ins. in any circle—

·7854 × square of diam. of circle = sq. ins.

Circumference of any circle = diam. × 3·1416 = circumference.

To ascertain weight of any column of water—

Area in sq. ins. × Feet in height × ·434 = Weight in lbs.

Or,

Area in cyld. ins. × Feet in height × ·341 = Weight in lbs.

To find the contents of a pipe—

Square the diam. in ins. × ·034 = Gals. in one foot length of pipe.

To find weight of water in 1 yard of pipe—

Square the diam. in ins. = Weight of water in lbs.

To find pressure in lbs. per sq. in. in pipes—

Head of water in feet × ·434 = Pressure in lbs.

To find the theoretical H.P. of a fall of water—

$$\frac{\text{No. of cub. ft. of water per sec.} \times \text{Height of fall in ft.} \times 62{\cdot}5}{550} = \text{H.P.}$$

USEFUL TABLES

Table I.—Areas of Circles in Square Inches

(From one-eighth inch to thirty inches Diameter, advancing by eighths.)

Dia.	·0	·⅛	·¼	·⅜	·½	·⅝	·¾	·⅞	Dia.	·0	·⅛	·¼.	⅜	·½	·⅝	·¾	·⅞
0	·0	·0122	·0490	·1104	·1963	·3068	·4417	·6013									
1	·7854	·9940	1·227	1·484	1·767	2·073	2·405	2·761	16	201·0	204·2	207·3	210·5	213·8	217·0	220·3	223·6
2	3·141	3·546	3·976	4·430	4·908	5·411	5·939	6·491	17	226·9	230·3	233·7	237·1	240·5	243·9	247·4	250·0
3	7·068	7·669	8·295	8·946	9·621	10·32	11·04	11·79	18	254·4	258·0	261·5	265·1	268·8	272·4	276·1	279·8
4	12·56	13·36	14·18	15·03	15·90	16·80	17·72	18·66	19	283·5	287·2	291·0	294·8	298·6	302·4	306·3	310·2
5	19·63	20·62	21·64	22·69	23·75	24·85	25·96	27·10	20	314·1	318·1	322·0	326·0	330·0	334·1	338·1	342·2
6	28·27	29·46	30·67	31·91	33·18	34·47	35·78	37·12	21	346·3	350·4	354·6	358·8	363·8	367·2	371·5	375·8
7	38·48	39·87	41·28	42·71	44·17	45·66	47·17	48·70	22	380·1	384·4	388·8	393·2	397·6	402·0	406·4	410·9
8	50·26	51·84	53·45	55·08	56·74	58·42	60·13	61·86	23	415·4	420·0	424·5	429·1	433·7	438·3	443·0	447·6
9	63·61	65·39	67·20	69·02	70·88	72·75	74·66	76·58	24	452·3	457·1	461·8	466·6	471·4	476·2	481·1	485·9
10	78·54	80·51	82·51	84·54	86·59	88·66	90·76	92·88	25	490·8	495·7	500·7	505·7	510·7	515·7	520·7	525·8
11	95·03	97·20	99·40	101·6	103·8	106·1	108·4	110·7	26	530·9	536·0	541·1	546·3	551·5	556·7	562·0	567·2
12	113·0	115·4	117·8	120·2	122·7	125·1	127·6	130·1	27	572·5	577·8	583·2	588·5	593·9	599·3	604·8	610·2
13	132·7	135·2	137·8	140·5	143·1	145·8	148·4	151·2	28	615·7	621·2	626·7	632·3	637·9	643·5	649·1	654·8
14	153·9	156·6	159·4	162·2	165·1	167·9	170·8	173·7	29	660·5	666·2	671·9	677·7	683·4	689·2	695·1	700·9
15	176·7	179·6	182·6	185·6	188·6	191·7	194·8	197·9	30	706·8	712·7	718·6	724·6	730·6	736·6	742·6	748·6

TABLE II.—SQUARES, CUBES, SQUARE AND CUBE ROOTS

Cube Roots.	Square Roots.	No.	Square.	Cube.
1·0000	1·0000	1	1	1
1·2599	1·4142	2	4	8
1·4422	1·7320	3	9	27
1·5874	2·0000	4	16	64
1·7099	2·2360	5	25	125
1·8171	2·4494	6	36	216
1·9129	2·6457	7	49	343
2·0000	2·8284	8	64	512
2·0800	3·0900	9	81	729
2·1544	3·1622	10	100	1000
2·2239	3·3166	11	121	1331
2·2894	3·4614	12	144	1728
2·3513	3·6055	13	169	2197
2·4101	3·7416	14	196	2744
2·4662	3·8729	15	225	3375
2·5198	4·0000	16	256	4096
2·5712	4·1231	17	289	4913
2·6207	4·2426	18	324	5832
2·6684	4·3588	19	361	6850
2·7144	4·4721	20	400	8000
2·7589	4·5825	21	441	9261
2·8020	4·6904	22	484	10648
2·8438	4·7958	23	529	12167
2·8844	4·8989	24	576	13824
2·9240	5·0000	25	625	15625
2·9624	5·0990	26	676	17576
3·0000	5·1961	27	729	19683
3·0365	5·2915	28	784	21952
3·0723	5·3851	29	841	24389
3·1072	5·4772	30	900	27000
3·1413	5·5677	31	961	29791
3·1748	5·6568	32	1024	32768
3·2075	5·7445	33	1089	35937
3·2396	5·8309	34	1156	39304
3·2711	5·9190	35	1225	42875
3·3019	6·0000	36	1296	46656

TABLE III.—LOSS OF PRESSURE IN LBS. PER SQUARE INCH FOR LENGTH OF 100 FEET

Gals. per Minute.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.	6 in.	8 in.	10 in.	12 in.	14 in.	16 in.	18 in.
5	3·3	0·84	0·31	0·12	...	...	...	...	...	...	...	...	...	...	...
10	13·0	3·16	1·05	0·47	0·12	...	...	...	...	...	...	...	...	...	...
15	28·7	6·98	2·38	0·97	...	...	...	...	...	...	...	...	...	...	...
20	50·4	12·3	4·07	1·66	0·42	...	...	...	...	...	...	...	...	...	...
25	78·9	19·0	6·40	2·62	...	0·21	0·10	...	...	...	...	...	...	...	...
30	...	27·5	9·15	3·75	0·91	...	...	...	...	...	...	...	...	...	...
35	...	37·0	12·4	5·05	...	...	...	...	...	...	...	...	...	...	...
40	...	48·0	16·1	6·52	1·60	...	...	...	...	...	...	...	...	...	...
45	...	...	20·2	8·15	...	...	...	...	...	...	...	...	...	...	...
50	...	...	24·9	10·0	2·44	0·81	0·35	0·09	...	...	...	...	...	...	...
75	...	...	56·1	22·4	5·32	1·80	0·74	...	...	...	...	...	...	...	...
100	...	...	...	39·0	9·46	3·20	1·31	0·33	0·05	...	...	...	...	...	...
125	...	...	...	...	14·9	4·89	1·99	...	...	...	...	...	...	...	...
150	...	...	...	...	21·2	7·0	2·85	0·69	0·10	...	...	...	...	...	...
175	...	...	...	...	28·1	9·46	3·85	...	...	...	...	...	...	...	...
200	...	...	...	...	37·5	12·47	5·02	1·22	0·17	...	...	...	...	...	...
250	...	...	...	...	...	19·66	7·76	1·89	0·26	0·07	0·03	0·01	...	...	...
300	...	...	...	...	...	28·06	11·2	2·66	0·37	0·09	0·04	...	...	...	...
350	...	...	...	...	...	...	15·2	3·65	0·50	0·12	0·05	0·02	...	...	...
400	...	...	...	...	...	...	19·5	4·73	0·65	0·16	0·06	...	...	...	...
450	...	...	...	...	...	...	25·0	6·01	0·81	0·20	0·07	0·03	...	...	...
500	...	...	...	...	...	...	30·8	7·43	0·96	0·25	0·09	0·04	0·017	0·009	0·005
750	...	...	...	...	...	...	...	...	2·21	0·53	0·18	0·08	...	...	...
1000	...	...	...	...	...	...	...	...	3·88	0·94	0·32	0·13	0·062	0·036	0·020
1250	...	...	...	...	...	...	...	...	...	1·46	0·49	0·20	...	...	...
1500	...	...	...	...	...	...	...	...	...	2·09	0·70	0·29	0·135	0·071	0·040
1750	...	...	...	...	...	...	...	...	...	...	0·95	0·38	...	...	...
2000	...	...	...	...	...	...	...	...	...	...	1·23	0·49	0·234	0·123	0·071

TABLE IV.—SHOWING WEIGHT OF WATER AT DIFFERENT TEMPERATURES

Temp. Fahr.	Wt. Cb. Ft. in Lbs.	Temp. Fahr.	Wt. Cb. Ft. in Lbs.	Temp. Fahr.	Wt. Cb. Ft. in Lbs.	Temp. Fahr.	Wt. Cb. Ft. in Lbs.
40	62·408	102	61·92	172	60·72	275	58·17
42	62·406	112	61·78	182	60·5	300	57·42
52	62·377	122	61·63	192	60·28	350	55·94
62	62·321	132	61·47	202	60·05	400	54·34
72	62·25	142	61·30	212	59·82	450	52·70
82	62·15	152	61·11	230	59·37	500	51·01
92	62·04	162	60·92	250	58·85	600	47·64

TABLE V.—WEIGHT AND QUANTITY OF WATER CONTAINED IN ONE FOOT LENGTH OF PIPE

Bore in Ins.	Water in Lbs.	Water in Gals.	Bore in Ins.	Water in Lbs.	Water in Gals.
¼	·0212	·0021	3	3·053	·3053
½	·0849	·0084	4	5·426	·5426
¾	·1900	·0190	5	8·480	·8480
1	·3408	·0340	6	12·21	1·221
1¼	·5300	·0530	8	21·71	2·171
1½	·7630	·0763	9	27·47	2·747
2	1·356	·1356	10	33·93	3·393
2½	2·120	·2120	12	49·00	4·900

Table VI

Initial Pressure, lbs. per sq. in.	Average Pressure of Steam in lbs. per sq. in. for the whole stroke.					
	Portion of stroke at which Steam is cut off.					
	¾	⅝	½	⅜	¼	⅛
5	4·8	4·6	4·2	3·7	3·0	1·9
10	9·6	9·2	8·4	7·4	5·9	3·8
15	14·5	13·8	12·7	11·2	8·9	5·8
20	19·3	18·4	16·9	14·8	11·9	7·7
25	24·1	22·9	21·1	18·6	14·9	9·6
30	29·0	27·5	25·4	22·3	17·9	11·5
35	33·8	32·1	29·6	26·0	20·8	13·5
40	38·6	36·7	33·8	29·7	23·8	15·4
45	43·4	41·3	38·1	33·5	26·8	17·3
50	48·3	45·9	42·3	37·2	29·8	19·2
60	57·9	55·1	50·7	44·6	35·7	23·1
70	67·6	64·3	59·2	52·1	41·7	26·9
80	77·3	73·5	67·7	59·5	47·7	30·8
90	86·9	82·7	76·1	66·9	53·6	34·6
100	96·6	91·9	84·6	74·4	59·6	38·5
110	106·2	101·1	93·1	81·8	65·6	42·3
120	115·9	110·3	101·5	89·3	71·5	46·2
130	125·6	119·4	110·0	96·7	77·5	50·0
140	135·2	128·6	118·5	104·1	83·4	53·9
150	144·9	137·8	126·9	111·6	89·4	57·7
160	154·6	147·0	135·4	119·0	95·4	61·6
180	173·9	165·4	152·3	133·9	107·3	69·3
200	193·2	183·8	169·3	148·8	119·2	70·7

Table VII.—Volume of Steam at Various Pressures

Pressure in lbs. per Sq. In.	Relative Volume of Steam to Water in Cub. Ins.	Pressure in lbs. per Sq. In.	Relative Volume of Steam to Water in Cub. Ins.
24	676	65	335
26	646	70	328
28	618	75	311
30	592	80	295
35	536	85	282
40	490	90	270
45	448	105	238
50	366	120	214
55	355	135	194
60	344	150	178

TABLE VIII.—THEORETICAL VELOCITY OF WATER IN FEET PER SECOND

Head Feet.	0	1	2	3	4	5	6	7	8	9
0	...	8·025	11·35	13·90	16·05	17·94	19·66	21·23	22·79	24·03
10	25·38	26·62	27·80	29·34	30·00	31·08	32·10	33·09	34·05	34·90
20	35·89	36·77	37·64	38·48	39·31	40·12	40·92	41·70	42·40	43·21
30	43·95	44·68	45·40	46·10	46·79	47·47	48·15	48·81	49·47	50·11
40	50·75	51·39	52·01	52·62	53·23	53·83	54·43	55·02	55·60	56·18
50	56·74	57·31	57·87	58·42	58·97	59·51	60·05	60·59	61·11	61·64
60	62·16	62·68	63·19	63·69	64·20	64·70	65·19	65·69	66·18	66·66
70	67·14	67·62	68·09	68·57	69·03	69·50	69·96	70·42	70·87	71·33
80	71·78	72·23	72·67	73·11	73·55	74·00	74·42	74·85	75·28	75·71
90	76·13	76·55	76·97	77·39	77·81	78·22	78·63	79·04	79·44	79·85

Head Feet.	100	200	300	400	500	600	700	800
0	80·25	113·49	139·00	160·50	179·44	196·57	212·32	226·98
25	89·72	120·37	144·67	166·44	183·88	200·62	216·08	230·50
50	98·29	126·87	150·13	170·24	188·20	204·60	219·77	233·97
75	106·16	133·08	155·40	174·90	192·43	208·50	233·41	237·38

TABLE IX.—DOWNWARD FLOW TURBINES

Head.	Velocity.	5 H.P.		10 H.P.		15 H.P.		20 H.P.		30 H.P.		40 H.P.		50 H.P.	
		Q.	R.	Q.	R.	Q.	R.	Q	R.	Q.	R.	Q.	R.	Q.	R.
2½	7·61	25	34	50	24	75	20	100	17	...	...	...	...	...	...
5	10·76	12½	81	25	57	38	47	50	41	75	33	100	28	126	26
10	15·22	6·3	180	12·5	128	19	105	25	90	38	75	50	64	63	58
15	18·65	4·2	319	8·4	226	12·6	185	17	160	25	131	33	113	42	100
20	20·52	...	...	6·3	329	9·3	273	12·6	232	19	194	25	164	31	148
25	24·07	...	...	...	...	7·5	358	10	310	15	253	20	220	25	196
30	26·37	...	...	...	...	...	...	8·4	380	12·6	310	17	268	21	240

H = Head in ft.

V = Velocity of Buckets in ft. per sec.

Q = Quantity in cub. ft. per sec.

R = Revolutions per min.

TABLE X.—PRESSURE OF WATER

The following table gives the pressure of water in lbs. per square inch for every foot in height up to 300 feet:—

Feet.	Press.	Feet.	Press.	Feet.	Press.	Feet.	Press.	Feet.	Press.	Feet.	Press.
1	0·43	43	18·62	85	36·82	127	55·01	169	73·20	211	91·39
2	0·86	44	19·05	86	37·25	128	55·44	170	73·64	212	91·83
3	1·30	45	19·49	87	37·68	129	55·88	171	74·07	213	92·26
4	1·73	46	19·92	88	38·12	130	56·31	172	74·50	214	92·69
5	2·16	47	20·35	89	38·55	131	56·74	173	74·94	215	93·13
6	2·59	48	20·79	90	39·98	132	57·18	174	75·37	216	93·56
7	3·03	49	21·22	91	39·42	133	57·61	175	75·80	217	93·99
8	3·46	50	21·65	92	39·85	134	58·04	176	76·23	218	94·43
9	3·89	51	22·09	93	40·28	135	58·48	177	76·67	219	94·86
10	4·33	52	22·52	94	40·72	136	58·91	178	77·10	220	95·30
11	4·76	53	22·95	95	41·15	137	59·34	179	77·53	221	95·73
12	5·20	54	23·39	96	41·58	138	59·77	180	77·97	222	96·16
13	5·63	55	23·82	97	42·01	139	60·21	181	78·40	223	96·60
14	6·06	56	24·26	98	42·45	140	60·64	182	78·84	224	97·03
15	6·49	57	24·69	99	42·88	141	61·07	183	79·27	225	97·46
16	6·93	58	25·12	100	43·31	142	61·51	184	79·70	226	97·90
17	7·36	59	25·55	101	43·75	143	61·94	185	80·14	227	98·33
18	7·79	60	25·99	102	44·18	144	62·37	186	80·57	228	98·76
19	8·22	61	26·42	103	44·61	145	62·81	187	81·00	229	99·20
20	8·66	62	26·85	104	45·05	146	63·24	188	81·43	230	99·63
21	9·09	63	27·29	105	45·48	147	63·67	189	81·87	231	100·06
22	9·53	64	27·72	106	45·91	148	64·10	190	82·30	232	100·49
23	9·96	65	28·15	107	46·34	149	64·54	191	82·73	233	100·93
24	10·39	66	28·58	108	46·78	150	64·97	192	83·17	234	101·36
25	10·82	67	29·02	109	47·21	151	65·49	193	83·60	235	101·79
26	11·26	68	29·45	110	47·64	152	65·84	194	84·03	236	102·23
27	11·69	69	29·88	111	48·08	153	66·27	195	84·47	237	102·66
28	12·12	70	30·32	112	48·51	154	66·70	196	84·90	238	103·09
29	12·55	71	30·75	113	48·94	155	67·14	197	85·33	239	103·53
30	12·99	72	31·18	114	49·38	156	67·57	198	85·76	240	103·96
31	13·42	73	31·62	115	49·81	157	68·00	199	86·20	241	104·39
32	13·86	74	32·05	116	50·24	158	68·43	200	86·63	242	104·83
33	14·29	75	32·48	117	50·68	159	68·87	201	87·07	243	105·26
34	14·72	76	32·92	118	51·11	160	69·31	202	87·50	244	105·69
35	15·16	77	33·35	119	51·54	161	69·74	203	87·93	245	106·13
36	15·59	78	33·78	120	51·98	162	70·17	204	88·36	246	106·56
37	16·02	79	34·21	121	52·41	163	70·61	205	88·80	247	106·99
38	16·45	80	34·65	122	52·84	164	71·04	206	89·23	248	107·43
39	16·89	81	35·08	123	53·28	165	71·47	207	89·66	249	107·86
40	17·32	82	35·52	124	53·71	166	71·91	208	90·10	250	108·29
41	17·75	83	35·95	125	54·15	167	72·34	209	90·53	260	112·79
42	18·19	84	36·39	126	54·58	168	72·77	210	90·96	300	134·49

From this table steam and other pressure gauges can be tested by erecting a small pipe against any available building or ship's mast, and filling it with water, the gauge being coupled on to the bottom end.

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